(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
31 May 2001 (31.05.2001)

PCT

(10) International Publication Number
WO 01/38882 A1

(51) International Patent Classification[7]: G01N 35/02

(21) International Application Number: PCT/US00/32041

(22) International Filing Date:
22 November 2000 (22.11.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
09/447,804 23 November 1999 (23.11.1999) US

(71) Applicant *(for all designated States except US)*: **BECTON DICKINSON AND COMPANY** [US/US]; 1 Becton Drive, Franklin Lakes, NJ 07417-1880 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **UFFENHEIMER, Kenneth** [US/US]; 24185 Summit Woods Drive, Los Gatos, CA 95033 (US). **BIERRE, Pierre** [US/US]; 980 Riesling Drive, Pleasanton, CA 94566 (US).

(74) Agents: **BUCZYNSKI, Joseph** et al.; Roylance, Abrams, Berdo & Goodman, L.L.P., 1300 19th Street, N.W., Suite 600, Washington, DC 20036 (US).

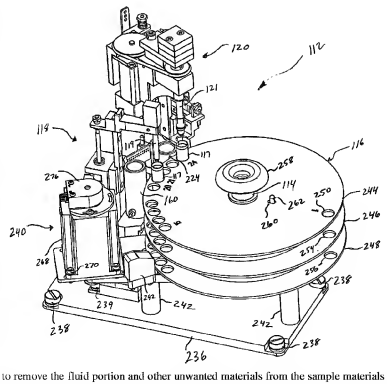
(81) Designated States *(national)*: JP, US.

(84) Designated States *(regional)*: European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR).

Published:
— *With international search report.*
— *Before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments.*

[Continued on next page]

(54) Title: APPARATUS AND METHOD FOR PROCESSING SAMPLE MATERIALS CONTAINED IN A PLURALITY OF SAMPLE TUBES



(57) Abstract: An apparatus and method for processing blood samples and other sample materials contained in a plurality of sample tubes (117) is capable of processing the samples by performing different steps of the processing operation, such as lysing and cell washing steps, on different sample tubes (117) simultaneously, so as to process the plurality of samples in parallel. The apparatus and method employs a sample tube rack (116) and a wash spindle (121). The sample tube rack (116) moves along a direction of movement and supports a plurality of sample tubes (117), each of the sample tubes (117) which contains a respective sample material. The wash spindle (121) temporarily removes each of the sample tubes (117) from the sample rack (116) and rotates the tube (117) to substantially separate the solid portion of the sample from the fluid portion while allowing the sample tube rack (116) to move along its direction of movement. The wash spindle (121) includes effluent openings sufficient in size, placement and number to remove the fluid portion and other unwanted materials from the sample materials in the sample tubes (117). The apparatus and method further employs a tube removal device (473) for efficiently removing the sample tubes from the wash spindle (12) when the processing is completed. The apparatus and method also employs a washing vessel (224) for cleaning the wash spindle (121) after it processes each sample tube (117).

WO 01/38882 A1

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

APPARATUS AND METHOD FOR PROCESSING SAMPLE MATERIALS CONTAINED IN A PLURALITY OF SAMPLE TUBES

BACKGROUND OF THE INVENTION

Field of the Invention:

The present invention relates to an apparatus and method for processing sample materials contained in a plurality of sample tubes. More particularly, the present invention relates to an apparatus and method for processing blood samples contained in a plurality of sample tubes by performing different steps of the processing operation, such as lysing and cell washing steps, on different sample tubes simultaneously, so as to process the plurality of fluid cell samples in parallel.

Description of the Related Art:

Many types of instruments exist for analyzing cells of a biological sample to detect for the presence of pathogens or other abnormalities. A flow cytometer, for example, photo-optically analyzes the fluorescent and light transmissive properties of reagent-stained cells contained in a sheath sample material stream to detect the presence of designated pathogens or other abnormalities in the cells.

Prior to introducing a cell sample into these types of instruments for analysis, it is generally necessary to treat the cell sample with specific reagents, dyes or other substances to enhance the properties of interest of the cells, and thus make those properties more readily identifiable. Also, for certain types of samples, such as blood samples, it may be necessary to separate the different components contained in the sample prior to analysis. For example, because the white blood cells of human blood typically manifest the presence of a pathogen or

disease, cell analyzing instruments generally will analyze the properties of only the white blood cells in a blood sample. Because of optical signal collection requirements, it is usually necessary to analyze stained white blood cells, or other reporter particles, in a clear isotonic solution free of residual, unbound reagents, dyes or chemicals. This requirement translates into the need to separate white blood cells from the soluble environment in which they reside at some point in the sample preparation process, and to replace this soluble environment with a clear, isotonic solution. This process is called "cell washing".

In preparations starting from samples rich in red blood cells, such as blood or marrow, the optical preparation of the sample requires that the red blood cells be rendered invisible. This is customarily done by lysing these red cells chemically, then washing the white cells, so that the final analate has been purged of everything except the white cells in clear solution. If not done, the optical properties of the preparation are compromised in several key areas. For example, the preparation can have a refractive index that is unmatched to a flow cytometer's enveloping sheath stream, which causes an artifact signal. Also, unwanted light scattering can occur as caused by red blood cells, lysed red blood cell ghosts, or platelets. Furthermore, a reduction of signal to noise ratio can result due to residual reagent which is not bound to any cell. A further advantage of cell washing is to enrich cells during the cell washing process, furthering the throughput and productivity of a flow cytometer instrument.

In a known cell washing method performed on blood samples, the collected blood samples are typically transferred by a lab technician from their collection tubes into respective sample tubes marked with the proper identification information corresponding to that on the collection tubes. The technician then manually adds the appropriate reagents, dyes and other substances, such as a lyse solution, to the blood samples, and allows the samples to incubate at the appropriate temperature for the appropriate amount of time. During this incubation period, the reagents or dyes will stain the white blood cells to thus enhance the properties of interest of those cells, while the lyse solution will cause the red blood cells to rupture.

After the incubation period has elapsed, the technician loads the sample tubes into a centrifuge device, and centrifuges or "spins down" the treated samples for the appropriate period of time. This centrifuging process causes the intact white blood cells to collect at the bottoms of the sample tubes to form a "pellet" of white blood cells in each of the sample

tubes. Once the centrifuging process has been completed, the technician removes the sample tubes from the centrifuge device, and uses a pipette or other appropriate suction device to extract the liquid content of the sample tubes while allowing the pellets of white blood cells to remain in their respective sample tubes. During this process, the technician also adds the appropriate wash fluids to the sample tubes to facilitate the washing process. These wash fluids are also removed from the sample tubes when the other residual fluids are extracted.

Once the cell washing process has been completed, the technician adds an appropriate fluid to each of the tubes to resuspend and break up the pellets in their respective tubes. The technician then loads the resuspended, washed white blood cell samples into the appropriate cell analyzing apparatus, such as a flow cytometer, for analysis.

Although this cell washing process generally provides satisfactory results, it is very labor intensive and time consuming. It is also common for a technician to accidentally extract some or all of a white blood cell pellet from its respective sample tube when extracting the other unwanted fluids and materials. In this event, the above process must be repeated on a remaining portion of the blood sample in the corresponding collection tube to create another white blood cell pellet. However, if no sufficient remaining blood sample exists, the patient must provide a fresh blood sample, which involves further delays.

A known automated cell washing apparatus is described in U.S. Patent No. 5,840,253, the entire contents of which are incorporated herein by reference. This known apparatus includes a carousel for housing a plurality of sample test tubes containing cell samples, and a cell washing instrument. The carousel rotates to sequentially position the sample test tubes for processing by the cell washing instrument. As each sample test tube is brought into position, the cell washing instrument performs the appropriate processing operations on the individual sample tube to remove the undesired components from the sample.

In particular, the cell washing instrument is inserted into the sample tube. A seal on the cell washing instrument functions to grip the inner wall of the sample tube to couple the cell washing instrument to the sample tube, and to create a seal between the fluid portion of the sample tube and the environment outside the sample tube. The cell washing instrument then spins the sample tube to cause the sample to collect along the interior side walls of the sample tube, and directs a washing fluid through the collected sample to remove the unwanted

materials while allowing the white blood cells to remain in the sample tube. The instrument then stops spinning the sample tube to allow the white blood cells to resuspend at the bottom of the sample tube, and performs the above process on the next sample tube in the carousel. After all of the sample test tubes have been processed, the test tubes can be removed from the carousel so that their respective samples can be loaded into and analyzed by an appropriate cell analyzing instrument.

Although this known cell washing apparatus generally is capable of sufficiently performing the necessary cell washing operations on a cell sample prior to analysis, the apparatus suffers from certain drawbacks. Specifically, prior to loading the sample test tubes into the apparatus, a lab technician must manually dispense the appropriate reagents, dyes and chemicals and, in particular, the lyse solution, into the samples. Additionally, because the cell washing instrument maintains the sample tube within its respective sample tube opening in the carousel when performing the cell washing process, the sample tube being processed prevents the carousel from rotating. Accordingly, the apparatus is incapable of performing any other operations which would require rotation of the carousel when a sample tube is being processed by the cell washing instrument. Also, spinning the sample tube without removing it from its respective opening in the carousel causes friction between the sample tube exterior and the wall of the carousel defining the sample tube opening, which can fracture the tube.

Furthermore, when the cell washing instrument is being inserted into the opening of a sample test tube to begin the cell washing process for that tube, the movement of the cell washing instrument is generally limited to the vertical direction. Therefore, if the carousel improperly aligns the opening of the sample test tube with the cell washing instrument, a large side load can be created between the cell washing instrument and the inner wall of the test tube when the cell washing instrument is being inserted into the test tube. This large side load can prevent the cell washing instrument from being inserted to its proper depth within the test tube, and could also cause the cell washing instrument to seize within the test tube. Furthermore, prolonged increased side loading can cause premature wear on the seal of the cell washing instrument.

In addition, the cell washing instrument does not include a purge feature for removing debris from its fluid delivery and removal passageways. Specifically, the cell washing

instrument lacks a drain or other waste removal feature into which the cell washing instrument can be inserted while a rinsing fluid is fed through its fluid delivery passageways to thus clean those passageways as well as the exterior of the portion of the instrument. Also, the cell washing instrument includes only two fluid removal passageways. Accordingly, velocity at which fluid flows through these two openings when being removed from the sample test tube can be high enough to inadvertently sweep away white blood cells along with the waste fluid. Furthermore, because these two openings are not distributed about the circumference of the cell washing instrument, dead zones can develop along the interior walls of the test tube in which little or no fluid flow occurs, resulting in insufficient washing of the white blood cells in those zones. The limited flow rate can also increase cell washing processing time, especially for larger volume sample test tubes.

Accordingly, a need exists for an apparatus and method for performing fluid processing on a sample material and, in particular, processing which includes cell washing operations, without the drawbacks of the known method and apparatus discussed above.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an efficient apparatus and method for processing sample materials contained in a plurality of sample tubes.

Another object of the present invention is to provide an apparatus and method for processing blood samples contained in a plurality of sample tubes by performing different steps of the processing operation, such as lysing, cell washing and mixing steps, on different sample tubes simultaneously, so as to process the plurality of blood samples in parallel.

A further object of the present invention is to provide an apparatus and method for effectively aligning the axis of a sample processing instrument, such as a wash spindle, of a sample processing apparatus with the axis of a sample tube including a sample material to be processed, to minimize side loading between the sample processing instrument and the inner wall of the sample tube when the sample processing instrument is being inserted into the sample tube.

Still another object of the present invention is to provide an apparatus and method for

effectively removing the sample processing instrument of a sample processing apparatus from the sample tubes to which the sample processing instrument is coupled to process the sample materials in the sample tubes.

A further object of the present invention is to provide an apparatus and method for cleaning one of the sample processing instruments, such as the wash spindle, of the sample processing apparatus after the instrument has processed a sample material in a sample tube loaded into the apparatus, while one or more other fluid processing instruments, such as a lysc dispenser probe, of the apparatus are processing sample materials in other sample tubes loaded into the apparatus.

A still further object of the present invention is to provide a cell wash apparatus comprising a wash spindle having a plurality of openings greater than two disposed about its circumference to reduce the flow velocity at which unwanted fluid and materials in the sample material are evacuated from the sample tube being processed by the cell washing instrument, to thus minimize loss of desired cells in the sample through the openings.

These and other objects of the invention are substantially achieved by providing an apparatus and method for processing sample materials, employing a sample tube rack and a wash spindle. The sample tube rack is adapted to move along a direction of movement and to support a plurality of sample tubes, each of which is adapted to contain a respective sample material, such as a blood sample. The wash spindle is adapted to temporarily remove any of the sample tubes from the sample tube rack and to manipulate the respective sample material in the removed sample tube to substantially separate a first portion, such as a lysed red blood cell portion, from a second portion, such as a white blood cell portion, while preventing the removed sample tube from restricting the sample tube rack from moving along its direction of movement. The sample tube rack is therefore capable of moving along its direction of movement when the wash spindle is manipulating the respective sample material in the removed sample tube.

The desired objects are also substantially achieved by providing an apparatus for processing a sample material, such as a blood sample, contained in a sample tube supported by a sample tube rack, comprising a wash spindle and a wash spindle alignment device. The wash spindle includes more than two openings, and is adapted to move in a first direction with

respect to an opening in the sample tube to project into the opening to temporarily couple to an interior surface of the sample tube. The wash spindle alignment device is adapted to permit the wash spindle to move in at least one direction transverse to the first direction when the wash spindle moves in the first direction, to minimize side loading between the wash spindle and the interior wall of the sample tube when the wash spindle enters the opening in the sample tube. The apparatus further comprises a device that is adapted to draw a first portion of the sample material, such as lysed red blood cells, through the openings in the wash spindle to substantially remove the first portion from the sample tube while allowing a second portion of the sample material, such as white blood cells, to remain in the sample tube. The apparatus also includes a sample tube stripper, adapted to assume a first position with respect to the wash spindle to permit the wash spindle to maintain contact with the sample tube, and further adapted to assume a second position to contact the sample tube to separate the sample tube from the wash spindle. The apparatus further comprises a vessel, which is adapted to receive at least a portion of the wash spindle after the wash spindle has uncoupled from the interior surface of the sample tube, and a fluid delivery device, which adapted to deliver a fluid into the vessel so that the fluid contacts and cleans the portion of the wash spindle in the vessel.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects, advantages and novel features of the invention will be more readily appreciated from the following detailed description when read in conjunction with the accompanying drawings, in which:

Fig. 1 is a perspective view of a fluid solution processing apparatus according to an embodiment of the present invention;

Fig. 2 is a perspective view of the apparatus shown in Fig. 1 with the door and control panel portion being position in their respective open positions;

Fig. 3 is a top view of the apparatus shown in Fig. 1 with the cover removed to expose the interior components;

Fig. 4 is a schematic diagram illustrating examples of the controller and electronic components included in the apparatus shown in Fig. 1;

Fig. 5 is a fluid diagram showing an example of the fluid system included in the apparatus shown in Fig. 1;

Fig. 6 is a perspective view of an example of the sample material processing portion of the apparatus shown in Fig. 1;

Fig. 7 is a top view of the sample processing portion shown in Fig. 6;

Fig. 8 is a perspective view of the sample processing portion shown in Fig. 6 with the carousel removed;

Fig. 9 is a top view of the sample processing portion shown in Fig. 8 with the carousel removed;

Fig. 10 is a front view of the sample processing portion shown in Fig. 8 with the carousel removed;

Fig. 11 is a bottom view of the carousel driving assembly of the sample processing portion shown in Figs. 6-10;

Fig. 12 is an exploded perspective view of the carousel driving assembly shown in Fig. 11;

Fig. 13 is a perspective view of the lyse probe assembly of the sample processing portion shown in Figs. 6-10;

Fig. 14 is a front perspective view of the lyse probe assembly shown in Fig. 13;

Fig. 15 is an exploded perspective view of the lyse probe assembly shown in Figs. 13 and 14;

Fig. 16 is a detailed perspective view of the lyse solution dispenser of the lyse probe assembly shown in Fig. 13-15;

Fig. 17 is rear view of the lyse solution dispenser shown in Fig. 16;

Fig. 18 is a cross-sectional view of the lyse solution dispenser shown in Fig. 16;

Fig. 19 is a detailed cross-sectional view of the distal portion of the lyse solution dispenser as taken from Fig. 18;

Fig. 20 is a reverse perspective view of the cell wash assembly of the cell processing portion shown in Figs. 6-10;

Fig. 21 is a front perspective view of the cell wash assembly shown in Fig. 20;

Fig. 22 is an exploded perspective view of the cell wash assembly shown in Figs. 20 and 21;

Fig. 23 is a perspective view of the cell wash spindle drive assembly of the cell wash assembly shown in Figs. 20-22;

Fig. 24 is an exploded perspective view of the cell wash spindle drive assembly shown in Fig. 23;

Fig. 25 is a cross-sectional view taken of the cell wash spindle assembly taken along lines 20-25 in Fig. 24;

Fig. 26 is a detailed view of the cell wash spindle assembly shown in Fig. 24;

Fig. 27 is a cross-sectional view of the cell wash spindle assembly shown in Fig. 26;

Fig. 28 is a detailed cross-sectional view of the distal end of the cell wash spindle assembly as taken from Fig. 27;

Fig. 29 is a detailed cross-sectional view of a first portion of the end assembly shown in Fig. 28;

Fig. 30 is a detailed cross-sectional view of a second portion of the end assembly shown in Fig. 28;

Fig. 31 is a cross-sectional view of the end assembly as taken along lines 31-31 in Fig. 26;

Fig. 32 is a flow diagram showing exemplary steps performed for processing fluid solutions using the apparatus shown in Fig. 1;

Fig. 33 is a flow diagram illustrating exemplary steps performed by the apparatus shown in Fig. 1 to process fluid solutions according to an embodiment of the present invention;

Fig. 34 is a diagrammatic view showing the shaft portion of the lyse solution dispenser of the lyse probe assembly shown in Figs. 13-15 positioned in its respective collection vessel;

Fig. 35 is a diagrammatic view showing the shaft portion of the lyse solution dispenser positioned above the vessel;

Fig. 36 is a diagrammatic view showing the shaft portion of the lyse solution dispenser positioned above a sample fluid tube;

Fig. 37 is a diagrammatic view showing the shaft portion of a lyse solution dispenser positioned in a sample tube;

Fig. 38 is a diagrammatic view of the cell wash spindle assembly of the cell wash assembly positioned in its respective collection vessel;

Fig. 39 is a diagrammatic view of the cell wash spindle assembly of the cell wash assembly positioned above the vessel;

Fig. 40 is a diagrammatic view of a spindle of the cell wash spindle assembly positioned above a sample tube;

Fig. 41 is a diagrammatic view of the cell wash spindle assembly positioned in the sample tube;

Fig. 42 is a diagrammatic view of the cell wash spindle assembly lifting sample tube out of the carousel;

Fig. 43 is a diagrammatic view showing the cell wash spindle assembly positioning the sample tube above the vessel;

Fig. 44 is a diagrammatic view showing the sample material in the sample tube coupled to the cell wash spindle assembly when the cell wash spindle assembly is at rest;

Fig. 45 is a diagrammatic view showing the sample material collected along the interior side walls of the sample tube when the sample tube is being rotated by the cell wash spindle assembly;

Fig. 46 is a detailed diagrammatic view of the sample material collected along the interior side walls of the sample tube when the sample tube is being rotated;

Fig. 47 is a diagrammatic view showing the sample material collected along the interior wall of the sample tube when the sample tube is being rotated and vented by the cell wash spindle assembly;

Fig. 48 is a diagrammatic view showing the sample material being washed by the cell wash spindle assembly;

Fig. 49 is a detailed diagrammatic view showing the sample material being washed by the cell wash spindle assembly;

Fig. 50 is a diagrammatic view of the washed sample material resuspended in the sample tube after the cell wash spindle assembly has stopped rotating;

Fig. 51 is a detailed diagrammatic view showing the resuspended washed sample material in the sample tube;

Fig. 52 is a diagrammatic view showing the tube stripper of the cell wash assembly removing the sample tube from the cell wash spindle assembly when the sample is being returned to the carousel; and

Fig. 53 is a diagrammatic view illustrating the cell wash spindle assembly returning the sample tube to its respective location in the carousel.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A sample material processing apparatus 100 according to an embodiment of the present invention is shown in Figs. 1-3. The apparatus includes a housing 102 having a transparent door 104 made of Plexiglas or any other suitable material, and a control panel portion 106. The control panel portion 106 includes, for example, an LCD touch display 108 via which a user can control operation of the apparatus 100. As shown, in particular, in Fig. 2, the transparent door 104 and control panel portion 106 are pivotally coupled to the housing 102 by hinge assemblies 110 and 111, respectively.

The apparatus 100 further includes a sample processing portion 112 which can be accessed when the door 104 is pivoted in an open position as shown in Fig. 2. As described in more detail below, the sample processing portion 112 includes, among other things, a rotating shaft assembly 114 for supporting a sample holder carousel 116 into which one or more sample tubes 117 can be loaded. The sample processing portion 112 further includes a probe mechanism 118 including a solution dispenser probe 119, and a cell wash assembly 120 including a cell wash spindle assembly 121. Details of the rotating shaft assembly 114, probe mechanism 118 and cell wash assembly 120 are described below.

The apparatus further includes a removable lyse solution container 122, a removable wash solution container 124, a removable spindle cleanse solution container 126 and a removable waste solution container 128. As described in detail below, the lyse solution container 122 supplies lyse solution, such as FACS Lysing reagent supplied by Becton-Dickinson and Company, to the probe mechanism 118. The wash solution container 124

supplies a suitable cell wash solution to the cell wash assembly 120. The spindle cleanse solution container 126 supplies a suitable spindle cleanse solution including, for example, FACS Rinse detergent and FACS Safe bleach solution supplied by Becton-Dickinson and Company, to the cell wash assembly 120. The waste solution container 128 collects residual solutions emitted from the probe mechanism 118 and cell wash assembly 120 as also described in detail below.

Lyse solution container 122, wash solution container 124 and spindle cleanse solution container 126 include caps 130, 132 and 134, respectively, which can be of the screw-on type to allow access to the interiors of their respective sample containers so that the appropriate fluids can be added to those sample containers when the sample containers are removed or, for example, when the control panel 106 is pivoted to expose the caps 130, 132 and 134. Similarly, waste solution container 128 includes a cap 136 which can also be of the screw-on type to allow a user to empty the waste solution container 128 when, for example, the waste solution container 128 is removed.

The apparatus 100 further includes a master controller 138 as shown, for example, in the schematic of Fig. 4. The master controller 138 can be a microcomputer or any other suitable controller as known in the art, and is coupled to the touch screen 107 of the control panel 106 via, for example, VGA and RS-232 connections. The master controller 138 is further coupled to a CAN bus 140 to the carousel drive control module 142, liquid transfer probe control module 144, syringe pump control module 146 and cell washer control module 148, the details of which are described below.

Specifically, the carousel drive control module 142 drives the spindle 114 under control of the master controller 138 to rotate the carousel tube holder 116. The master controller 138 and liquid transfer probe control module 144 control components such as the air compressor 150 (see Fig. 3), air valves (not shown), and fluid control valves (see Fig. 5 below) to control movement of the probe mechanism 118 and delivery of the lyse solution by the probe mechanism 118 as discussed in detail below. The syringe pump control module 148, in particular, controls the flow of lyse solution to the probe mechanism 118 as discussed below. The master controller 138 and the cell wash control module 148 controls the components such as the air compressor 158, air valves (not shown), fluid control valves and

pumps (see Fig. 5) and the like for controlling movement of the cell wash assembly 120 and delivery of the wash and spindle cleanse solution by the cell wash assembly 120.

Fig. 5 is an example schematic diagram of the fluid delivery and removal components of the apparatus 100. As shown, the solution dispenser probe 119 of probe mechanism 118 is coupled by a conduit 152 to lyse solution container 122. A syringe pump 153 is coupled along conduit 152 and is controlled by master controller 138 to provide the lyse solution from the lyse solution container 122 to the solution dispenser probe 119 at the appropriate flow rate to dispense lyse solution into a sample tube 117 as discussed below. Optionally, the solution dispenser probe 119 can further be coupled by a conduit 154 to an auxiliary solution container 156 which can contain, for example, another solution different than lyse solution, or additional lyse solution. An auxiliary syringe pump 158 can be coupled along conduit 154 and be controlled by master controller 138 and syringe pump control module 146 to provide the other solution from the auxiliary solution container 156 to the solution dispenser probe 119 at the appropriate flow rate to dispense the other solution into a sample tube 117 as desired.

A receptacle 160 is associated with the probe mechanism 118 to collect lyse solution expelled from the solution dispenser probe 119 when the solution dispenser probe 119 is being primed as discussed in detail below. The receptacle 160 is coupled by conduits 162 and 164 to the waste solution container 128. A two-way valve 166 as known in the art is coupled along conduit 162 to open and close conduit 162 for reasons discussed below. A pump 168 is coupled along conduit 164 and is controlled, for example, by the controller 138 to create a negative pressure in conduits 162 and 164 to draw the lyse solution from the receptacle 160 into the waste solution container 128. A pressure transducer 170 is coupled to conduit 164 to monitor pressure in the conduit 164 and provide signals to, for example, controller 138 indicative of the monitored pressure, which enables the controller 138 to monitor and control the system vacuum level, and to detect for leaks which could be present in the system conduits, or in the sample tube 117 being processed by the cell wash spindle assembly 121 as discussed in detail below. Also, pressure switch 172 is placed between pump 168 and waste solution container 128 to monitor system waste pressure.

As further illustrated, the cell wash spindle assembly 121 of the cell wash assembly 120 is coupled via conduits 174 and 176 to the wash solution container 124. A two-way valve

178 as known in the art is coupled along conduit 176 to open and close conduit 176 for reasons discussed below. Optionally, conduit 174 can be coupled to optional wash solution containers 180 and 182 via conduits 184 and 186, respectively. Two two-way valves 188 and 190 are coupled along conduits 184 and 186, respectively, to open and close conduits 184 and 186 for reasons discussed below. Conduit 174 is further coupled to pump 168 and conduit 164 via conduit 192. A two-way valve 194 is coupled along conduit 192 to open and close conduit 192 for reasons discussed below.

The cell wash spindle assembly 121 is further coupled via conduits 196 and 198 to a leak test port 200, and via conduits 196 and 202 to a vent port 204. Two two-way valves 206 and 208 are coupled along conduits 198 and 202, respectively, to open and close conduits 198 and 202 for reasons discussed below. Furthermore, restrictor 210 is coupled along conduit 198 to restrict flow along conduit 198 to a desired rate.

The cell wash spindle assembly 121 is further coupled via conduits 212 and 214 to pump 168, conduit 164 and conduit 192. The cell wash spindle assembly 121 is also coupled via conduits 212 and 216 to a pump 218. Two two-way valves 220 and 222 are coupled along conduits 214 and 216, respectively, to open and close conduits 214 and 216 for reasons discussed below. Pump 218 is controlled, for example, by the controller 138 to pump spindle cleanse solution from the spindle cleanse solution container 126 to the cell wash spindle assembly 121 via conduits 216 and 212 as discussed in detail below.

A receptacle 224 is associated with the cell wash assembly 120 to collect wash solution expelled from the cell wash spindle assembly 121 when the cell wash spindle assembly 121 is being cleaned as discussed in detail below. The receptacle 224 is coupled via conduit 226 to the pump 218. A two-way valve 228 is coupled along conduit 226 to open and close conduit 226 for reasons discussed below. Also, a restrictor 230 is coupled along conduit 226 to restrict fluid flow to receptacle 224. Pump 218 is controlled, for example, by the controller 138 to pump wash solution from the wash solution container 126 to the receptacle 224 via conduit 226 as discussed in detail below.

The receptacle 224 is further coupled by conduits 232 and 164 to the pump 168. A two-way valve 234 is coupled along conduit 232 to open and close conduit 232 for reasons discussed below. The pump 168 is controlled, for example, by the controller 138 to create a

negative pressure in conduits 232 and 164 to draw the wash solution from the receptacle 224 into the waste solution container 128.

Details of the sample processing portion 112 of the apparatus 100 will now be described. As shown, for example, in Figs. 6-10, the sample processing portion 112 includes a base 236 which can be removably mounted to the interior base of housing 102 (see Figs. 1-3) by screws 238 or the like. The probe mechanism 118 and cell wash assembly 120 are mounted to the base 236 by screws 239 or any other suitable mounting device.

A carousel drive assembly 240 is mounted on posts 242 which are coupled to the base 236 by screws (not shown) or any other suitable device. The carousel drive assembly 240 drives the shaft assembly 114 to which the carousel 116 can be removably mounted. As illustrated, the carousel 116 includes a plurality of plates 244, 246 and 248 which are circular or substantially circular in shape and include tube holder openings 250, 252 and 254, respectively, into which can be loaded sample tubes 117 containing sample materials to be processed by the apparatus 100 as discussed below. As indicated, the openings 250, 252 and 254 are substantially aligned with each other so that the tubes 117 pass through all three respective openings when loaded into the carousel 116. However, the diameters of openings 254 are slightly smaller than the diameters of their corresponding openings 250 and 252 to prevent the sample tubes 117 from falling out of the bottom of the carousel 116. In this example, each plate 244, 246 and 248 of the carousel 116 includes 40 openings 250, 252 and 254, respectively, into which can be loaded 40 sample tubes 117. However, the carousel 116 can be configured to support any practical number of sample tubes 117 having any practical size or shape. Also, the carousel 116 can alternatively be configured as a linear tube transport system which delivers the tubes 117 to the solution probe 119 and cell wash assembly 120 in a linear manner.

As can be appreciated from Figs. 6-10, the carousel 116 includes openings (not shown) which pass through the centers of plates 244, 246 and 248 and which are aligned with or substantially aligned with each other for receiving the shaft of shaft assembly 114 when the carousel 116 is loaded into the apparatus 100. A cap 258 can be mounted onto the shaft of shaft assembly 114 to secure the carousel 116 to the shaft. Each plate 244, 246 and 248 also includes a respective slotted opening 260 which are aligned with or substantially aligned with

each other and receive a reference pin 262 of the shaft assembly 114 which, in this example, references the position of openings 250, 252 and 254 identified as tube position 1. For reasons discussed in detail below, the outer diameter of reference pin 262 has a magnitude slightly less than the width of slotted opening 260, to allow for some movement or "play" between the carousel 116 and the shaft assembly 114 in the direction of rotation of the carousel 116.

The details of the carousel drive assembly 240 will now be described. As shown in Figs. 6-10 and in more detail in Figs. 11 and 12, the carousel drive assembly 240 includes a plate 264 which is mounted to posts 242 by screws 266 or any other suitable device. The carousel drive assembly 240 further includes a drive motor 268, such as a stepper motor, that is mounted to the plate 264 by mounting screws 270 which pass through slotted openings 272 in the plate 264 and couple to plates 274 as shown, for example, in Fig. 12. An encoder assembly 276 as known in the art is coupled to mounting 268 by screws 278 and controls driving of the motor 268 under control of the controller 138 and carousel drive control module 142 (see Fig. 4).

The motor 268 includes a shaft 280 that passes through an opening 282 in plate 264 and couples to a pulley 284. A drive belt 286 passes around pulley 284 and around a pulley 288 coupled to shaft assembly 114. As shown, the shaft assembly 114 is also mounted to plate 264 by screws 290 or any other suitable fasteners, with the reference pin being mounted to the shaft assembly 114 by nut 291. Accordingly, the motor 268 drives the shaft assembly 114 via pulleys 284 and 288 and drive belt 286 under the control of the controller 138 and drive module 142.

The carousel drive assembly 240 further includes sensors 292 and 294 which sense for the presence of tubes 117 at the tube positions 1 through 40 in the carousel 160 as described below. The sensors 292 and 294 are mounted to the plate 264 by screws 296 or any other suitable fasteners. The carousel drive assembly 240 further includes a sensor 298 for sensing the home position of the carousel 116 as described in detail below. The sensor 298 is mounted to plate 264 by screws 296 and 300, mounting plate 302 and nuts 304 as illustrated.

The probe mechanism 118 is shown in more detail in Figs. 13-19. As discussed above, the probe mechanism 118 includes solution dispenser probe 119 for dispensing lyse solution into a sample tube 117 as discussed in detail below. As shown, in particular, in Figs. 16-19,

the solution dispenser probe 119 includes a shaft portion 308 connected to a housing portion 310. The shaft portion 308 includes two conduits 312 and 314 that are secured in the shaft portion 308 by a gasket 316 made of rubber, silicone or the like. The conduits 312 and 314 are in communication with openings 316 and 318, respectively, in housing portion 310. In this example, opening 318 is connected to conduit 152 while opening 316 can be connected to conduit 154 (see Fig. 5). Accordingly, as described in detail below, conduit 314 can be used to deliver lyse solution from lyse solution container 122 while conduit 113 can be used to deliver another solution from auxiliary solution container 156 (see Fig. 5).

Returning to Figs. 13-15, the solution dispenser probe 119 is mounted to an arm member 320. Specifically, the shaft portion 308 of solution dispenser probe 119 passes through an opening 322 in arm member 320. A screw 324 is used to close the portions of arm member 320 forming opening 322 about shaft portion 308 of solution dispenser probe 119 to secure the solution dispenser probe 119 to the arm member 320.

The arm member 320 is mounted to a vertical rail assembly 326 by a bracket 328 and screw 330. It is noted that the vertical rail assembly 326 includes a bracket portion 332 and a rail portion 334 which is slideable with respect to the bracket portion 332. Because the arm member 320 is mounted to the rail portion 334, the arm member 320 and, thus, the solution dispenser probe 119, is slideable with respect to bracket portion 332. The bracket portion 332 of vertical rail assembly 326 is mounted to bracket 336 by screws 338 as shown. A printed circuit board assembly 340 is also mounted to the bracket 336 by screws 342.

As further shown, an air cylinder assembly 344 is mounted to bracket 336. Specifically, air cylinder assembly 344 has a shaft 346 which can be driven from a retracted position to an extended position by compressed air provided from air pump 150 (see Fig. 3) under the control of, for example, controller 138 and liquid transfer probe control module 144 (see Fig. 4). As indicated in Fig. 15, the shaft 346 passes through a threaded flanged bushing 348, so that the threaded flanged bushing 348 can screw onto the threaded nose 349 of the air cylinder assembly 344. The threaded nose 349 of the air cylinder assembly 344 onto which the bushing 348 has been screwed are secured into an opening 350 in bracket 336 by a set screw 351, to thus couple the air cylinder assembly 344 to the bracket 336.

An arrangement of screws 352 and spacer 354 couple the shaft 346 to bracket 328 as shown. Specifically, the bottom screw 352 is screwed onto the threaded end of shaft 346. The threaded end of shaft 346 is then passed through an opening 355 in bracket 328, and through spacer 354, so that the spacer 354 is positioned in the opening 355 when the bracket 328 and spacer 354 are supported by the bottom screw 352. The top screw 352 is then screwed onto the threaded end of the shaft 346 to couple the shaft 346 to the bracket 328. Accordingly, shaft 346 is coupled via bracket 328 to the rail portion 334 of rail assembly 326 as well as to arm member 320 and solution dispenser probe 119. As described in more detail below, the air cylinder assembly 344 is driven to move the shaft portion 346 between retracted and extended positions to move the lyse solution dispenser in a vertical direction L_V.

The probe mechanism 118 further includes an air cylinder assembly 356 that is driven by compressed air provided from air pump 150 under the control of controller 138 as described in more detail below. The air cylinder assembly 356 includes a base portion 358 and a rectangular air cylinder 360 having a shaft 362 that moves in and out of the rectangular air cylinder 360 in response to compressed air provided into connection ports 364. Mounting screws 365 are inserted through the rectangular air cylinder 360 to mount the rectangular air cylinder 360 to the base portion 358. A rail assembly 366 having a rail portion 368 and a mounting portion 370 is connected to the base portion 358 by screws 372 as shown.

As further illustrated, the bracket 336 is coupled to a bracket 374 by screws 376, and the bracket 374 is coupled to the shaft 362 of rectangular air cylinder 360 by a shoulder screw 377. That is, as shown in Figs. 13 and 15, bracket 374 has an opening 378 and a counterbored portion 379 surrounding the opening. In this example, bracket 374 has a thickness of about 0.125 inches, but only a thickness of about 0.106 inches at the counterbored portion 379. The shoulder screw 377 has a head 377-1, a shoulder portion 377-2, and a threaded shaft 377-3. In this example, shoulder portion 377-2 has a height of about 0.125 inches. The threaded shaft 377-3 is received into a threaded end of shaft 362 to couple the bracket 374 to the shaft 362 so that the shoulder portion 377-2 is in opening 378 in the bracket 374. Accordingly, the difference between the 0.106 inch thickness of counterbored portion 379 of the bracket 374 and the 0.125 inch height of shoulder portion 377-2 allows for about 0.019 inches of movement or "play" between the bracket 374 and the end of the shaft 362 along direction L_H

shown in Fig. 14. Alternatively, instead of having a counterbored portion 379, the entire thickness of bracket 374 can be reduced to about 0.106 inches to achieve the same amount of movement or "play".

As further shown in Figs. 13-15, the bracket 336 is connected to mounting portion 370 of rail assembly 366 by screws 380, so that rail portion 368 can pass through a slotted opening 381 in bracket 374 when the mounting portion 370 slides along rail portion 368 as discussed in more detail below. A magnet 382 is mounted to base portion 358 of air cylinder assembly 356, and magnetic sensors 384 are mounted to bracket 336 by screws 386. Accordingly, the sensors 384 are used to sense their respective locations with respect to the magnet 382 as the air cylinder assembly 356 is driven to drive the bracket 336 in a horizontal direction and provide signals indicative thereof to the controller 138, which interprets these signals to determine the horizontal position of the bracket 336. It can be understood that by moving the bracket 336 in a horizontal direction, the solution dispenser probe 119 is also moved along a horizontal direction L_H as will be described in more detail below. It can be further appreciated that the approximately 0.019 inches of movement or "play" between the bracket 374 and the end of the shaft 362 along direction L_H shown in Fig. 14 provides for the same amount of movement or "play" between solution dispenser probe 119 and air cylinder assembly 358.

Additionally, as shown in Fig. 15, the receptacle 160 is mounted to the base 358 of air cylinder assembly 356 by bracket 388 and screws 390 and 392. Furthermore, connection 394 is coupled to vessel 160 and to conduit 162 (see Fig. 5) so that fluid can be drained from receptacle 160 as described below.

Details of the cell wash assembly 120 will now be described with references to Figs. 20-30. As discussed above, the cell wash assembly 120 includes a cell wash spindle assembly 121 which is coupled to wash spindle driver assembly 395. The wash spindle driver assembly 395 is coupled to a rail assembly 396. Specifically, rail assembly 396 includes a fixed portion 398 and a movable portion 400 which is slideable with respect to the fixed portion 398. The wash spindle assembly 121 is coupled to the movable portion 400 by screws 402 and could therefore slide in a vertical direction with respect to the fixed portion 398 as discussed in more detail below.

The cell wash assembly 120 further includes an air cylinder assembly 404 having a cylinder portion 406 and a shaft 408. As discussed in detail below, compressed air can be applied to the cylinder portion 406 by the air pump 150 under control of, for example, controller 138 and cell washer control module 148 (see Figs. 3 and 4) to move the shaft 408 between a retracted position where most of the shaft 408 resides in the cylinder portion 406, and an extended position where most of the shaft 408 is extended outside the cylinder portion 406. The cylinder portion 406 also includes a threaded nose portion 409, the purpose of which is described below.

As further illustrated, the cell wash assembly 120 includes a bracket 410. The fixed portion 398 of the rail assembly 396 is coupled to the bracket 410 by screws 412. Also, a bracket 414 is coupled to bracket 410 by screws 416. Air cylinder assembly 404 is mounted to bracket 410 by a nut 417 as shown, for example, in Fig. 22. That is, shaft 408 and threaded nose portion 409 pass through an opening 418 in bracket 414, and nut 417 screws onto threaded nose portion 409 to mount the air cylinder assembly 404 to bracket 414. Bracket 414 thus couples air cylinder assembly 404 to the bracket 410.

As further illustrated, the shaft 408 is coupled to the wash spindle driver assembly 395 by bracket 534 (see Figs. 23 and 24), nut 419 and spring retainer 420. Specifically, nut 419 screws onto the threaded end of shaft 408, and supports the bracket 534 of wash spindle driver assembly 395 when the threaded end of shaft 408 is passed through opening 421 in bracket 534 as shown. A compression spring 422 is slid onto the end of shaft 408 and rests on the top of bracket 534, while spring retainer 420 retains spring 422 in a compressed state against the top of bracket 534. Accordingly, as described in more detail below, the shaft 408 is moved between the retracted position to the extended position to move the wash spindle driver assembly 395 in a vertical direction Wv (see Fig. 21) with respect to bracket 410. For purposes discussed in detail below, the compression spring 422 is compressed to about 1.5 LB of compression force, and allows wash spindle driver assembly 395 to have about 1/16 inches of movement or "play" with respect to the shaft 408 along the vertical direction Wv to facilitate coupling of the cell wash spindle assembly 121 to a sample tube 117.

The cell wash assembly 120 further includes an air cylinder assembly 426 comprising a base portion 428 and rectangular air cylinder 430 having a shaft 432 that moves in and out of

the rectangular air cylinder 426 in response to compressed air provided into connection ports 433 from air compressor 150 under the control of, for example, controller 138 and cell washer control module 148. The base portion 428 is mounted to base 236 by screw 239 (see, for example, Fig. 8), while rectangular air cylinder 430 is mounted to the base portion 428 by mounting screws 434. A rail assembly 435 having a rail portion 436 and a mounting portion 438 is coupled to the base portion 428 of air cylinder 426. Specifically, rail portion 436 is coupled to base portion 428 by screws 440 as shown, so that rail portion 436 is fixed with respect to base portion 428, while mounting portion 438 can slide along rail portion 436.

As further illustrated, bracket 410 is coupled to mounting portion 438 of rail assembly 434 by screws 444. The bracket 410 is also coupled to a bracket 446 by screws 448, and the bracket 446 is coupled to the shaft 432 of rectangular air cylinder 430 by a shoulder screw 449. That is, as shown in Figs. 20 and 22, bracket 446 has an opening 450 and a counterbored portion 451 surrounding the opening. In this example, bracket 446 has a thickness of about 0.125 inches, but only a thickness of about 0.106 inches at the counterbored portion 451. The shoulder screw 449 has a head 449-1, a shoulder portion 449-2, and a threaded shaft 449-3. In this example, shoulder portion 449-2 has a height of about 0.125 inches. The threaded shaft 449-3 is received into a threaded end of shaft 432 to couple the bracket 446 to the shaft 432 so that the shoulder portion 449-2 is in opening 450 in the bracket 446. Accordingly, the difference between the 0.106 inch thickness of counterbored portion 451 of the bracket 446 and the 0.125 inch height of shoulder portion 449-2 allows for about 0.019 inches of movement or "play" between the bracket 446 and the end of the shaft 432 along direction W_H shown in Fig. 21. Alternatively, inside of having a counterbored portion 451, the entire thickness of bracket 446 can be reduced to about 0.106 inches to achieve the same amount of movement or "play". It can be further appreciated that when mounting portion 438 slides along rail portion 436, the end of rail portion 436 can pass through slotted opening 452 in bracket 446.

Accordingly, when the shaft 432 of rectangular air cylinder 430 is driven, the bracket 446 and bracket 410 are driven to move in a horizontal direction indicated by arrow W_H. Hence, the air cylinder assembly 404 and wash spindle driver assembly 395 are moved along this horizontal direction. A magnet 453 is positioned on base member 428, and sensors 454

are coupled to bracket 410 by screws 456 to detect the magnet 453 and thus provide signals to the controller 138 indicating the horizontal position of the bracket 410 .

The cell wash assembly 120 further includes an air cylinder assembly 458 having a cylinder portion 460 and a shaft 462. A connector 464 of cylinder portion 460 is coupled to receive air from air pump 150 under control of, for example, controller 138 and cell washer control module 148 to position the shaft 462 in a retracted or an extended position. The air cylinder 458 is coupled to a bracket 466 by a screw 467 that screws onto the threaded nose 468 of the air cylinder 458. The bracket 466 couples the air cylinder 458 to bracket 410 by screws 469. The shaft 462 is coupled to a tube stripper assembly 470 by nuts 471 and spacer 472. Specifically, tube stripper assembly 470 includes a tube striper portion 473 and a rail assembly 474 having a mounting portion 476 and a rail portion 478. The mounting portion 476 is coupled to the bracket 410 by screws 467, while the tube stripper portion 473 is coupled to rail portion 478 by screw 482. Accordingly, when the shaft 462 is driven between the retracted and extended positions, the tube stripper portion 473 is moved along the horizontal direction S for purposes described below.

As further illustrated, a circuit board assembly 484 is coupled to bracket 410 by screws 486. Furthermore, vessel 224 is coupled to base portion 428 of air cylinder assembly 426 by a bracket 488 and screws 490 and 492. Flow restrictor/fitting 494 and fitting 496 are connected to vessel 224 and are further connected to conduits 230 and 232 (see Fig. 5), respectively, for purposes discussed below. Additionally, mounting screws 498 are inserted into rectangular air cylinder 430 of air cylinder assembly 426.

Details of the cell wash spindle assembly 121 will now be described with reference to Fig. 24. As discussed above, the cell wash spindle driving assembly 395 includes a base 500 having an opening 502 through which a portion of cell wash spindle assembly 121 passes. The cell wash spindle assembly 121 is rotatably supported in opening 502 by bearings 504 as shown. As discussed in more detail below, the cell wash spindle assembly includes an outer cylinder 506, a tube centering feature 508, a seal 510, an air tube 512, and a fluid tube 514.

As further illustrated, a motor 516, which is controlled by, for example, controller 138 and cell washer control module 148 (see Fig. 4), is mounted to base 500 by screws 518. A pulley 520 is mounted to the center shaft of the motor 516 and is thus driven by the center

shaft. A pulley 522 is mounted to the cell wash spindle assembly 121 above the upper bearing 504 and is spaced from the top surface of upper bearing 504 by a spacer 524. A drive belt 526 passes around pulleys 520 and 522 so that the motor 516 can drive the pulley 520 which in turn drives pulley 522 and thus rotates cell wash spindle assembly 121 for reasons discussed below.

A circuit board assembly 528 is coupled to base 500 by bracket 530 and screws 532. Additional brackets 534 and 536 are coupled to base 500 by screws 538. A seal support bracket 540 is coupled to the top of base 500 by shaft guide 542 and collar 544 as shown. The seal support bracket 540 has an opening 546 through which outer cylinder, air tube 512 and fluid tube 514 of cell wash spindle assembly 121 pass. As shown in Fig. 24, a face seal assembly 548 is mounted to the top surface of seal support bracket 540. An O-ring 550 and sapphire ring 552 have respective openings therein to allow air tube 512 and fluid tube 514 to pass therethrough. Sapphire ring 552 rests on the end of outer cylinder 506, and O-ring 550 rests on top of sapphire ring 552.

The bottom of face seal assembly 548 has a countersunk opening therein (not shown) which receives O-ring 550, sapphire ring 552 and the end of shaft 506, and communicates with opening 554 in the side of face seal assembly 548. The opening 554 therefore communicates with a passage in cell wash spindle assembly 121 formed between the inner surface of outer cylinder 506 and the outer surface of air tube 512, while the o-ring 550 and sapphire ring 552 prevent leakage between the end of the outer cylinder 506 and the countersunk area of the face seal assembly 548. Also, the sapphire ring 552 allows the outer cylinder 506 to rotate as driven by bearings 504. As further shown, face seal assembly 548 has an opening 556 in its top surface through which the air tube 512 and fluid tube 514 project.

As shown in Fig. 25, because the inner diameter of outer cylinder 506 is larger than the outer diameter of air tube 512, a passage 558 extends between those surfaces along the length of outer cylinder 506. Furthermore, because the inner diameter of air tube 512 is greater than the outer diameter of fluid tube 514, a passage 560 exists between those two surfaces which extends along the length of air tube 512. Furthermore, a passage 562 extends along the length

of fluid tube 514. A fitting 564 is inserted into opening 554 (Fig. 24) to couple conduit 212 (see Fig. 5) to opening 554 and thus, to passage 558 via opening 554.

Returning to Fig. 24, an air housing 566 having openings 568 and 570 therein is mounted on top of face seal assembly 548 as shown. An O-ring 572 having an opening therein is received into a countersunk opening (not shown) in the bottom of air housing 566, along with the top end of air tube 512. The opening in O-ring 572 allows opening 556 to communicate via the opening (not shown) in the bottom of air housing 566 with opening 570. Hence, when the air housing 566 is mounted to the face seal assembly 548, the passage 560 between air tube 512 and fluid tube 514 is placed into communication with opening 570, while the fluid tube 514 passes through opening 568. The O-ring 572 thus prevents leaks between the end of the air tube 512 and the countersunk portion of the opening (not shown) in the bottom of the air housing 566. A fitting 574 is inserted into opening 570 to couple opening 570 to conduit 196 (see Fig. 5) for reasons discussed below.

A fluid housing 576 is mounted to the top of air housing 566 as shown, with an O-ring 578 positioned in a countersunk opening (not shown) in the bottom of the fluid housing 576. The O-ring 578 has an opening to allow the passage 562 in fluid tube 514 to communicate with an opening 580 in fluid housing 576, while the O-ring 578 prevents leaks between the end of the fluid tube 514 and the countersunk surface of the opening (not shown) in the bottom of fluid housing 576.. Screws 582 pass through openings in fluid housing 576, air housing 566 and phase seal assembly 548 and are received in openings in seal support bracket 542 to secure the seal support bracket 540, phase seal assembly 548, air housing 566 and fluid housing 576 together. A fitting 583 is inserted into opening 580 to couple opening 580 to conduit 174 (see Fig. 5) for reasons discussed below.

Further details of the cell wash spindle assembly 121 will now be described with reference to Figs. 26-31. As discussed above, the cell wash spindle assembly 121 includes an outer cylinder 506, a center portion 508, an air tube 512 and a fluid tube 514. The cell wash spindle assembly 121 further includes an end assembly 584, the details of which are described with reference to Figs. 28-31. As illustrated in Fig. 28, end assembly 584 includes a first portion 586 that is mounted to the end of outer cylinder 506, and a second portion 588 that is received into an opening in first portion 586.

As shown in Fig. 29, the first portion 586 has a first opening 590 for receiving the distal end of outer cylinder 506, and a second opening 592 which is in communication with the first opening 590 and receives a portion of the second portion 588 as shown in Fig. 28. In this example, the first portion 586 includes tapered edges 594 and has overall diameter D1 of about 0.360 inches. The first portion 586 also includes a narrow portion 596 having an outer diameter D2 of about 0.2505 inches in this example. The diameter D3 taken at the distal end of the first portion 586 is about 0.210 inches in this example, while the inner diameter D4 at the narrowed portion 596 is about 0.2015 inches in this example. A ring-shaped seal 597, such as those made by Bal Seal corporation, is mounted to first portion 586 about the narrow portion 596 as shown in Fig. 28.

Further details of the second portion 588 are shown in Fig. 30. Specifically, the second portion 588 includes a narrow portion 598 which is received into second opening 594 of the first portion 586, and a distal portion 600. As illustrated, the distal portion includes a plurality of openings 602 which communicate with the central passage 604 of the second portion 588, and thus communicate with the passage 558 between the inner surface of outer cylinder 506 and the outer surface of air tube 512 (see Fig. 25) for purposes described below. In this example, the diameters D5 through D11 are as follows: D5 is about 0.330 inches, D6 is about 0.250 inches, D7 is about 0.220 inches, D8 is about 0.187 inches, D9 is about 0.200 inches, D10 is about 0.129 inches and D11 is about 0.109 inches. The central passage 604 communicates with narrower central passage 606. As shown in Fig. 28, support bearing 608 and seal 610, such as the type made by Bal Seal corporation, are fitted into the central passage 606. The O-rings 608 and 610 each have openings therein for receiving the air tube 512 as shown.

In this example, the second portion 588 includes eight openings 602 which are spaced equally about the circumference of the distal portion 600 at equal or substantially equal intervals. Accordingly, in this example, the openings 602 are spaced about 45° apart about the circumference of distal portion 600. However, any suitable number of openings having any diameter and spacing about the circumference of distal portion 600 can be present. A cross-sectional view of the second portion 588 showing openings 602 is set forth in Fig. 31. The operation of the apparatus will now be described.

Fig. 32 is a flow diagram illustrating steps performed for processing sample materials, which includes steps performed by the apparatus 100. In step 1000, the sample materials that have been collected in collection vessels are logged in by a lab technician. The samples can also be pre-processed at this time in step 1010, which includes adding any reagents, dyes, or other appropriate substances to the samples. In step 1020, a Mab reagent is added to the sample tubes 117, then in step 1030, the respective samples are transferred via a pipette or the like from the respective sample collection vessels to their respective designated sample tubes.

In step 1040, the sample tubes 117 are then placed in a vortex mixer (not shown) or the like to mix the Mab reagent with the samples. In step 1050, the sample tubes 117 are loaded into the carousel 116 which is shown, for example, in Figs. 1-3. For purposes for this explanation, it is assumed that at least three sample tube 117, each including respective sample materials containing a fluid and solid portions, are loaded into the carousel 116. It is noted that these tubes can be loaded adjacent to each other, or at any location in the carousel 116. Furthermore, in this example, the carousel 116 can accommodate up to 40 sample tubes 117.

The processing then proceeds to the steps which specifically involve the apparatus 100. That is, in step 1060, the technician loads the carousel 116 containing the sample tubes 117 into apparatus 100. The technician can then enter the appropriate processing protocol via touch screen 107 and close the door 104 on the apparatus 100 in step 117. At this time, the processing proceeds to step 1080 where the apparatus processes the samples in the sample tubes 117.

An example of the sample processing operations performed by apparatus 100 will now be described with reference flow chart in Fig. 33. Once the carousel 116 has been loaded onto the shaft assembly 114 as shown, for example, in Fig. 1-3, the controller 138 and carousel drive module 142 control the carousel in step 1090 to rotate along direction R (clockwise -- see Fig. 3) to allow the sensors 292 and 294 to sense the presence of sample tubes at tube positions 1 through 40. Once carousel 116 has completed an entire revolution so that the sensors 292 and 294 have determined in which sample tube positions sample tubes 117 are present, the controller 138 stores this information in a memory, such as a random access memory (RAM), and controls the drive motor 268 to drive the shaft assembly 114 to rotate the carousel 116 to its home position in step 1100. Once the detector 298 has detected that the

carousel 116 has been rotated to its home position, the sample tube processing begins.

When carousel 116 is being rotated, the solution dispenser probe 119 and the cell wash spindle assembly 121 are positioned within their respective vessels 160 and 224. The processing proceeds to step 1110 where, for example, the controller 138 and syringe pump control module 146 (see Fig. 4) controls syringe pump 153 to begin pumping lyse solution from lyse solution container 122 to prime the syringe pump 153 and conduit 314 of solution dispenser probe 119 with lyse solution. During this time, the controller 138 controls the valve 166 (see Fig. 5) to be open, while all other valves remain closed, and drives pump 168 to draw the lyse solution from the vessel 160 through conduits 162 and 164 into waste solution container 128.

The processing then proceeds to step 1120 where the controller 138 and carousel drive module 142 control the motor 268 to drive the spindle assembly to rotate the carousel to position the appropriate sample tube 117 at the solution dispenser probe 119 as shown, for example, in Fig. 34. As also shown, the sample tube 117 contains a sample material 612 therein, which in this example is a blood sample including a fluid portion (e.g., plasma) and a solid portion (e.g., red and white blood cells). Alternatively, the sample material can be sample beads, such as yellow/green beads manufactured by Polysciences, or far red beads manufactured by Molecular Probes, Inc., or any other beads suitable for use with a flow cytometer. The sample material can also be any material including components having different densities. In step 1130, the controller 138 and, for example, liquid transfer probe control module 144, control the air pump 150 and the appropriate valves (not shown) to supply compressed air through the appropriate conduits (not shown) to rectangular air cylinder 360 of air cylinder 358 and to air cylinder assembly 344 to move the shaft portion 308 of the solution dispenser probe 119 out of the vessel 160 as shown in Fig. 35, in the horizontal direction L_H to be positioned over the opening of the sample tube 117 as shown in Fig. 36, and then down into the sample tube 117 as shown in Fig. 37.

In step 1140, the controller controls syringe pump 153 to pump an appropriate predetermined amount of lyse solution from lyse solution container 122 through conduit 314 in solution dispenser probe 119, to thus dispense the appropriate amount of lyse solution into sample tube 117. The lyse solution causes the red blood cells to rupture and release their

hemoglobin into the sample 612. To allow the lyse solution to act on the red blood cells in this manner, the processing can cease for an incubation period of, for example, 10 minutes if desired.

The processing then continues to step 1150 where the controller 138 and liquid transfer probe control module 144 control the air pump 150 and the appropriate valves (not shown) to provide compressed air through the appropriate conduits to rectangular air cylinder 360 of air cylinder assembly 356 and to air cylinder 344 to move the shaft portion 308 of solution dispenser probe 119 out of the sample tube 117 as shown in Fig. 36, back above the vessel 160 as shown in Fig. 35, and then back down into the vessel as shown in Fig. 34.

The processing then proceeds to step 1160 where the controller 1388 controls the motor 268 to drive the shaft assembly 114 to incrementally rotate the carousel 116 in a direction opposite to that shown by arrow R in Fig. 3, and then back in the direction of arrow R. This rotation of the carousel 116 is a cycloidal mixing process which mixes the sample material in tube 117 with the lyse solution that has been added to the tube 117. This mixing process also agitates the sample materials in the other sample tubes 117 loaded into the carousel 116 and thus, helps to maintain the cells in the sample materials in a suspended state.

Specifically, during the cycloidal mixing process, the carousel 116 is rotated in one direction (e.g., counterclockwise) in increments equal to about 1/10th of full rotation or, in other words, 36° increments. During each incremental rotation, the movement of the carousel 116 is accelerated and then decelerated in a very controlled manner, to mix the sample materials in the sample tubes 117 in an efficient, controlled manner. After several incremental rotations have been performed in the first direction, the carousel 116 is rotated in a similar incremental manner in the opposite direction (e.g., clockwise). These incremental rotations, along with the controlled acceleration and deceleration of the rotation during each incremental rotation, is sufficient to resuspend cells which, for example, became adhered to the inner walls of the sample tubes 117, and also mixes the cells with any materials (e.g., lyse solution, reagents and so on), that were added to the samples.

The processing then proceeds to step 1170 where the controller 138 and drive module 142 control the motor 268 to drive the shaft assembly 114 to rotate the carousel 116 in the direction indicated by arrow R to position the sample tube 117 into which the lyse solution

was dispensed to a position for processing by the cell wash assembly 120 as shown, for example, in Fig. 38. The processing proceeds to step 1180 where the controller 138 controls air pump 150 and the appropriate valves to supply compressed air to rectangular air cylinder 430 of air cylinder 426 and to air cylinder 404 to move the wash spindle assembly 121 upward out of the vessel 224 as shown in Fig. 39, in a horizontal direction W_H to a position over the opening of sample tube 117 as shown in Fig. 40, and then down into sample tube 117 as shown in Fig. 41. During this movement, the tube stripper portion 473 is positioned out of the path of movement of the wash spindle assembly 121.

It is further noted that the features described above pertaining to the motor 268, reference pin 262 and slotted opening 260 (see Fig. 6) provide for some movement or "play" between the wash spindle assembly 121 and the tube 117 along the direction of movement of the carousel 116 which can be referred to as the "x direction". Also, the movement or "play" provided by the arrangement between the shoulder screw 449 and bracket 446 (see Figs. 20 and 22) provides for some movement or "play" between the wash spindle assembly 121 and the tube 117 along a direction radial of the carousel 116, which can be referred to as the "y direction". Furthermore, the movement or "play" provided by the compression spring 422 (see Figs. 20-22) provides for some movement or "play" between the wash spindle assembly 121 and the tube 117 in the vertical direction, which can be referred to as the "z direction". This movement or "play" in the x, y and z directions enables the axis of the wash spindle assembly 121 to align with the axis of the sample tube 117 so that the wash spindle assembly 121 can engage the sample tube 117 while mimizing side load on the interior surface of the tube.

That is, when the cell wash spindle assembly 121 enters the sample tube 117, the seal 597 contacts the inner surface of the sample tube 117. If the axis of the cell wash spindle assembly 121 is misaligned with the axis of the sample tube 117 in the x-direction, the play between the reference pin 262 of the drive shaft assembly 114 and the slotted opening 260 in the carousel 116 will allow for movement of the axis of the sample tube 117 in the x-direction as the cell wash spindle assembly 121 is entering the tube 117. Furthermore, nature of the stepper motor 268 will allow for some rotation of the drive shaft assembly 114 due to the force applied by the cell wash spindle assembly 121 when entering the tube 117, while acting in a

spring-like manner to urge the drive shaft assembly 114 back to the position at which it was set by the stepper motor 268 prior to entry of the cell wash spindle assembly 121 into the tube 117. This movement will also assist in aligning the axis of the cell wash spindle assembly 121 with the axis of the tube 117 in the x direction, and thus reduce side loading.

Also, if the axis of the cell wash spindle assembly 121 is misaligned with the axis of the sample tube 117 in the y-direction, the play between the shoulder screw 449 and bracket 446 allows for play in the y-direction as discussed above. This play will assist in aligning the axis of the cell wash spindle assembly 121 with the axis of the tube 117 in the y direction, and thus reduce side loading.

Furthermore, the play in the z-direction permitted by the spring 422 will assure that the cell wash spindle assembly 121 has reached the appropriate depth with the sample tube 117. This assures that the seal 597 of the cell wash spindle assembly 121 has made a sufficient seal the inner surface of the sample tube 117, and thus has removably secured the cell wash spindle assembly 121 to the sample tube 117.

Once the cell wash spindle assembly 121 has been removably secured to the sample tube 117 as described above, the controller 138 and cell washer control module 148 then control the air pump 150 and appropriate valves to provide compressed air to the rectangular air cylinder 430 of the air cylinder 426 and to the cylinder portion 406 of air cylinder assembly 404 to lift the cell wash spindle assembly 121 as shown in Fig. 42. The sample tube 117 is thus lifted out of the carousel 116, and moved to a position above vessel 224 as shown in Fig. 43. At this time, the sample material 612 is at rest at the bottom of the sample tube 117 as shown in Fig. 44.

The processing then proceeds to step 1190 where the controller 138 to drive motor 516 which drives pulleys 520 and 522 to rotate the cell wash spindle assembly 121 and thus rotate the tube 117 as shown in Fig. 45. As shown in more detail in Fig. 46, this rotating of the tube 117 causes the sample material 612 having a fluid portion 614 and a cell portion 616 to migrate and be suspended along the vertical side walls of sample tube 117 due to centripetal force. This initial rotating or spinning operation can occur for a period from about one second to about nine seconds as desired. It is noted that during this spin-up phase, rotating sample tube 117 generates an outward acceleration of about 500g, which forces the cells in the sample

material up against the interior wall of the sample tube 117. Because the cells only have to travel about 1.0 mm, they reach the interior wall of the sample tube 117 within several seconds (e.g., about 2 to about 5 seconds), depending on the cell or particle size, cell or particle density and so on.

As further shown in the flowchart of Fig. 33, the processing also proceeds to step 1200 where the controller 138 determines from the number of the tube position whether the tube being rotated by the cell wash spindle assembly 121 is the last tube to be processed in the carousel 116. If the tube 117 is the last tube, the processing will proceed from steps 1190 and 1200 to step 1210 where the cell wash assembly 120 will continue processing the sample tube 117 as discussed below.

However, if the controller 138 determines that the sample tube being processed is not the last tube to be processed in the carousel 116, a parallel processing will occur while the sample tube 117 is being rotated by the cell wash spindle assembly 121. That is, as the sample tube 117 is being rotated in step 1190 and further rotated and processed in step 1210, the controller 138 and drive module 142 in step 1220 controls the motor 268 to rotate the carousel 116 to position the next sample tube 117 for processing by the probe mechanism 118 in a manner similar to that discussed above with regard to step 1120. The parallel processing will continue at step 1230 where the controller 138 and liquid transfer probe control module 144 will position the solution dispenser probe 119 into this next sample tube 117 in a manner similar to step 1130 above.

The parallel processing proceeds to step 1240 where the syringe pump 153 is controlled to dispense lyse solution into this next sample tube 117 in a manner similar to that discussed above with regard to step 1140. The processing will then continue to step 1250 where the controller 138 will control the air pump 150 and the appropriate valves to provide compressed air to the rectangular air cylinder 360 of air cylinder 358 and to air cylinder 344 to return the shaft portion 308 of the solution dispenser probe 119 into vessel 160. The processing will also continue to step 1260 where the controller 138 will control the motor 268 to drive the shaft assembly 114 to rotate the carousel 116 to perform the cycloidal mixing process as described above with regard to step 1160. The processing will then proceed to step 1210 which is in progress as will now be described.

Specifically, in step 1210, the cell wash spindle assembly 121 continues to rotate the sample tube 117. However, at this time, the controller 138 also controls the valve 208 (see Fig. 5) to be in the open position while the other valves remain closed to allow the interior of the sample tube 117 being rotated to vent to the outside atmosphere via passage 560 in the cell wash spindle assembly 121 and conduits 196 and 202. This exhaust process can occur for up to about 0.50 seconds, while the sample material 612 remains collected along the inner wall of sample tube 117 as shown in Fig. 47.

The controller 138 then controls valves 178 and 220 to be open, while the other valves shown in Fig. 5 are closed. The controller 138 then controls waste pump 168 to begin pumping, which creates a vacuum in conduits 176, 174, 212, and 214, and in the interior of sample tube 117. This vacuum draws wash solution out of wash solution container 124, through conduits 176 and 174, through fluid housing 576 and through fluid tube 514 into sample tube 117 as shown in Fig. 49. As further shown in Fig. 49, this wash fluid proceeds up the side walls of sample tube 117 to wash the white blood cells being held along the side walls due to the spinning of sample tube 117. However, the flow of this wash fluid is sufficient to wash away the unwanted fluid portion of the sample material 612, such as the plasma and hemoglobin, as well as the ruptured red blood cells. This unwanted portion of the sample material 612 passes through the eight openings 602 in the end assembly 584 of cell wash spindle assembly 121, through passage 558, through the opening 554 in seal support bracket 540 (see Fig. 24) and through conduits 212 and 214 to the waste pump 168 and into the waste solution container 128. This washing process can continue for about one to about twelve seconds, or for as long as about 15 seconds or longer if deemed necessary. The washing process can remove, for example, unbound antibody reagent, lower density solid components such as red blood cell ghosts and platelets, or an enveloping fluid for the purposes of replacing the removed enveloping fluid with another enveloping fluid.

The number and distribution of openings 602 reduces the velocity at which the unwanted portion of the sample material 612 flows out of the sample tube 117, and thus minimizes inadvertent evacuation of the white blood cells. Also, the number and distribution of openings 602 minimizes dead zones along the inner surface of the sample tube 117 at which

insufficient cell washing occurs. Accordingly, the number and distribution of openings 602 allows for efficient and effective cell washing with minimal white cell loss.

Once the washing process has been completed, the controller 138 and cell washer control module 148 controls the motor 516 to stop rotating cell wash spindle assembly 121 and thus abruptly stop rotating sample tube 117. When the sample tube 117 stops rotating, the cell or particles remaining in the sample tube after the cell washing process become resuspended at the bottom of the sample tube as shown in Figs. 50 and 51.

The processing then proceeds to step 1270 where the controller 138 and drive module 142 control the motor 268 to drive the shaft assembly 114 to rotate the carousel 116 so that the sample tube position on the carousel 116 from which the sample tube 117 was removed is in position for the sample tube 117 to be returned. The processing proceeds to step 1280 where the controller 138 controls the air pump 150 and appropriate valves to supply compressed air to the rectangular air cylinder 430 of the air cylinder 426 and to the air cylinder 404 to position the cell wash spindle assembly 121 and sample tube 117 attached thereto to a position over the tube loading position on the carousel 116 as shown, for example, in Fig. 42. The compressed air then controls air cylinder 404 to lower the cell wash spindle driving assembly 395 downward to lower the cell wash spindle assembly 121 to return sample tube 117 to its appropriate opening in carousel 116 as shown in Fig. 41.

The processing then proceeds to step 1290 where the controller 138 controls the air pump 150 and appropriate valves to provide compressed air to air cylinder 458 to drive the tube stripper portion 473 into position as shown, for example, in Fig. 52. The processing then proceeds to step 1300 where the controller controls air pump 150 and the appropriate valve to provide compressed air to cylinder 404 to lift the cell wash spindle driving assembly 395 in the direction W_V so that the tube stripper portion 473 contacts the top of sample tube 117 and thus removes the sample 117 from the cell wash spindle assembly 121. In other words, the sample tube 117 is then free to drop off of the end of cell wash spindle assembly 121 and fall back into its opening in carousel 116 due to gravity as shown in Fig. 53.

The processing then proceeds to step 1310 where the controller controls compressed pump 150 and appropriate valves to supply compressed air to the rectangular air cylinder 430 of air cylinder assembly 426 and to air cylinder 404 to return the cell wash spindle assembly

121 into vessel 124 as shown, for example, in Fig. 38. The cell wash spindle assembly 121 and, in particular, the end assembly 584 of the cell wash spindle assembly 121 is washed. That is, the controller 138 controls the motor 516 (see Fig. 24) to rotate spindles 520 and 522 and thus rotate cell wash spindle assembly 121 while cell wash spindle assembly 121 is in the vessel 224. At this time, the controller 138 controls the valves 222, 228 and 234 to be open, while all other valves are closed. The controller controls pump 218 to begin pumping spindle cleanse solution from the spindle cleanse solution container 126 through conduits 116 and 112, through opening 554 in face seal assembly 548, and through passage 558 and out of openings 602 in the end assembly 584 of the cell wash spindle assembly 121. The pump 218 also pumps spindle cleanse solution from the spindle cleanse solution container 126 through conduit 226 and into vessel 224 through fitting 494.

Because the opening of fitting 494 in vessel 224 is approximately even with the position of end assembly 584 in the vessel 224, the exterior of end assembly 584 is also rinsed by the spindle cleanse solution being provided by conduit 226. At this time, the controller 138 is also controlling pump 168 to pump and thus create a vacuum in conduits 232 and 164. Accordingly, the spindle cleanse solution being collected into the vessel 224 is drawn through conduits 232 and 164 to pump 168 and into the waste solution container 128. Once this rinsing process is complete, which occurs for several seconds, the controller determines in step 1320 whether any more sample tubes 117 require processing.

As discussed above, processing was begun on the second sample tube in steps 1220 through 1260 by the probe mechanism 118 in parallel with the spinning and cell washing operations performed by the cell wash assembly 120. Accordingly, the processing returns to step 1170 where the controller 138 controls the motor 268 to drive the shaft assembly 114 to rotate the carousel 116 to position this next tube for processing by the cell wash assembly 120, and the steps discussed above are repeated. These steps are repeated until all of the tubes in the carousel 116 have been processed or, in other words, until the cell washing process has been performed on all the sample materials 612 in the tubes 117.

When the processing determines in step 1320 that above steps have been performed on all of the sample materials 612, the processing proceeds to step 1330 shown in the flowchart in Fig. 32. During this step, the technician can then open the door 104 to the apparatus 100 and

remove the carousel 116 for loading onto a further processing unit, such as a FACSLoader unit manufactured by Becton Dickinson and Company. The FACSLoader unit can then be used to provide the sample tubes 117 containing the washed cell samples to, for example, a flow cytometer, which photo-optically analyzes the fluorescent and light transmissive properties of the washed cell samples to detect for the presence of designated pathogens or other abnormalities in the cells.

Although only a few exemplary embodiments of the present invention have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the following claims.

What is claimed is:

1. An apparatus for processing sample materials, comprising:

a sample tube rack, adapted to move along a direction of movement and to support a plurality of sample tubes, each of which is adapted to contain a respective sample material including at least first and second components of different density; and

a spindle, adapted to temporarily remove a sample tube from said sample tube rack and to rotate said sample tube to substantially separate said first component from said second component while allowing said sample tube rack to move along said direction of movement;

said sample tube rack being adapted to move along said direction of movement when said spindle is rotating said sample tube.

2. An apparatus as claimed in claim 1, wherein:

said sample tube rack comprises a plurality of sample tube supporting portions, each adapted to support a respective one of said sample tubes; and

said spindle removes said any sample tube from its respective sample tube supporting portion of said sample tube rack prior to manipulating said respective sample material in said any sample tube, and is further adapted to return said any sample tube to its respective sample tube supporting portion after manipulating said respective sample material.

3. An apparatus as claimed in claim 1, further comprising:

a spindle aligning apparatus, adapted to substantially align an axis of said spindle component with an axis of said sample tube when said spindle is being inserted into said sample tube.

4. An apparatus as claimed in claim 1, wherein said spindle comprises:

a fluid dispenser, adapted to dispense a fluid into said any sample tube when said spindle is manipulating said respective sample material in said any sample tube; and

a fluid remover, adapted to remove at least a portion of said fluid portion and at least a portion of said second material from said any sample tube.

5. An apparatus as claimed in claim 1, further comprising:

a fluid dispenser, adapted to dispense a second fluid into another of said sample tubes supported by said sample tube rack while said spindle is manipulating said respective sample material in said any sample tube.

6. An apparatus as claimed in claim 1, further comprising:

a sample tube stripper, adapted to assume a first position with respect to said spindle to permit said spindle to remove said any sample tube from said sample tube rack, and further adapted to assume a second position to contact said any sample tube to separate said any sample tube from said spindle.

7. An apparatus as claimed in claim 1, wherein:

said sample tube rack is substantially circularly shaped and is adapted to support said sample tubes at intervals along a circumferential direction; and

said direction of movement is along said circumferential direction.

8. An apparatus as claimed in claim 1, wherein:

said sample material is a blood sample, said first portion includes white blood cells, and said second portion includes a waste portion of said blood sample other than white blood cells; and

said spindle assembly manipulates said blood sample to separate said white blood cells from said waste portion.

9. An apparatus for processing sample materials, comprising:

a sample tube rack, adapted to move along a direction of movement and to support a plurality of sample tubes, each of which is adapted to contain a respective cell sample; and

a driver, adapted to drive said sample tube rack to move along said direction of movement in a plurality of incremental movements, such that said driver accelerates and

decelerates movement of said sample tube rack during each of said incremental movements so as to agitate and mix said cell samples in said sample tubes.

10. An apparatus as claimed in claim 9, further comprising:

a fluid dispenser, adapted to dispense a fluid into said sample tubes before or after said driver drives said sample tube rack in said incremental movements.

11. An apparatus as claimed in claim 9, further comprising:

a spindle, adapted to temporarily remove from said sample tube rack any said sample tube, and further adapted to manipulate said respective cell sample in said any sample tube to substantially separate a first portion of said cell sample from a second portion of said cell sample while preventing said any sample tube from restricting said sample tube rack from moving along said direction of movement.

12. An apparatus as clamed in claim 9, wherein:

said sample tube rack is substantially circularly shaped and is adapted to support said sample tubes at intervals along a circumferential direction; and

said direction of movement is along said circumferential direction.

13. A spindle assembly, adapted to manipulate a sample material in a sample tube to separate a first component of said sample material from a second component of said sample material, said first and second components having different densities, said spindle assembly comprising:

a shaft assembly, adapted to couple to and rotate said sample tube to substantially separate said first component from said second component; and

a material removal conduit, having a plurality of openings greater than two which are adapted to communicate with an interior of said sample tube when said shaft assembly couples to said sample tube, said openings being adapted to provide passageways through which said second component is evacuated from said sample tube.

14. A spindle assembly as claimed in claim 13, wherein:

said sample material is a blood sample, said first component includes white blood cells, and said second component includes a waste portion of said sample material other than white blood cells;

said shaft assembly is adapted to separate said white blood cells from said waste portion of said sample material; and

said openings are adapted to provide passageways through which said waste portion is evacuated from said sample tube.

15. An apparatus for processing a sample material contained in a sample tube supported by a sample tube rack, comprising:

a spindle, adapted to move in a first direction with respect to an opening in said sample tube, to project into said opening to temporarily couple to an interior surface of said sample tube; and

a spindle alignment device, adapted to substantially align an axis of said spindle with an axis of said sample tube when said spindle is projecting into said opening in said sample tube, to substantially minimize a loading force applied to said interior surface of said sample tube by said spindle.

16. An apparatus as claimed in claim 15, further comprising:

a spindle moving device, adapted to move said spindle when said spindle is coupled to said interior surface of said sample tube, to remove said sample tube from said sample tube rack.

17. An apparatus as claimed in claim 15, further comprising:

a sample tube contacting device, adapted to assume a first position with respect to said spindle to permit said spindle to maintain contact with said sample tube, and further adapted to assume a second position to contact said sample tube to separate said sample tube from said spindle.

18. An apparatus as claimed in claim 15, wherein said spindle is further adapted to uncouple from said interior surface of said sample tube, and said apparatus further comprises:

a vessel, adapted to receive at least a portion of said spindle after said spindle has uncoupled from said interior surface of said sample tube; and

a fluid delivery device, adapted to deliver a fluid into said vessel so that said fluid contacts said portion of said spindle in said vessel.

19. An apparatus for removing a sample tube from a spindle, comprising:

a sample tube stripping device; and

a driver, adapted to selectably drive said sample tube stripping device to assume a first position with respect to said spindle to permit said spindle to maintain contact with said sample tube, and to assume a second position at which said sample tube stripping device is adapted to contact said sample tube to separate said sample tube from said spindle.

20. An apparatus as claimed in claim 19, wherein:

said driver drives said sample tube stripping device to assume said second position which is in a path through which said spindle moves said sample tube.

21. A method for processing sample materials contained in respective sample tubes supported by a sample tube rack which is adapted to move along a direction of movement, each of said sample material including at least first and second components of different densities, said method comprising the steps of:

temporarily removing a sample tube from said sample tube rack;

while said any sample tube is temporarily removed from said sample tube rack, rotating said sample tube to substantially separate said first component from said second component while allowing said sample tube rack to move along said direction of movement; and

while said spindle is rotating said sample tube, moving said sample tube rack along said direction of movement.

22. A method as claimed in claim 21, further comprising the step of:

returning said sample tube to said sample tube rack after manipulating said respective sample material.

23. A method as claimed in claim 21, further comprising the step of:

substantially aligning an axis of said spindle with an axis of said sample tube when said spindle is being inserted into said sample tube.

24. A method as claimed in claim 21, wherein said manipulating step comprises the steps of:

dispensing a fluid into said sample tube; and

removing at least a portion of said fluid along with at least a portion of said second component from said any sample tube.

25. A method as claimed in claim 21, further comprising the step of:

dispensing a second fluid into another of said sample tubes supported by said sample tube rack while performing said rotating step.

26. A method as claimed in claim 25, wherein:

said second fluid is a red blood cell lysing reagent.

27. A method as claimed in claim 21, wherein:

said first component of said sample material includes stained white blood cells;

said second component of said sample material includes at least one of unbound antibody reagent, red blood cell ghosts, platelets; and

said rotating step rotates said sample tube substantially to separate said stained white blood cells from said second component of said sample material.

28. A method as claimed in claim 21, wherein:

said first component of said sample material includes stained white blood cells;

said second component of said sample material includes a first enveloping liquid enveloping said white blood cells;

said rotating step rotates said sample tube to separate said white blood cells from said first enveloping liquid; and

said method further comprises the steps of:

removing said separated first enveloping liquid from said sample tube; and

adding a second enveloping liquid to said sample tube to enable said second enveloping liquid to envelope said white blood cells in said sample tube.

29. A method as claimed in claim 21, wherein:

said first component includes beads, and said second component includes a reminder of said sample material other than said beads; and

said manipulating step separates said beads from said remainder of said sample material.

30. A method as claimed in claim 21, further comprising the step of:

selectably positioning a sample tube stripper in contact with said sample tube after performing said manipulating step, to allow gravity to return said sample tube to said sample tube rack.

31. A method as claimed in claim 21, wherein:

said sample tube rack is substantially circularly shaped and is adapted to support said sample tubes at intervals along a circumferential direction; and

said moving step moves said sample tube rack along said circumferential direction.

32. A method as claimed in claim 21, wherein:

said sample material is a blood sample, said first component includes white blood cells, and said second component includes a waste portion of said blood sample other than white blood cells; and

said manipulating step manipulates said blood sample to separate said white blood cells from said waste portion.

33. A method for mixing a cell sample included in a sample tube loaded in a sample tube rack which is adapted to move along a direction of movement, said method comprising the steps of:

driving said sample tube rack to move along said direction of movement in a plurality of incremental movements; and

accelerating and decelerating movement of said sample tube rack during each of said incremental movements so as to agitate and mix said cell sample in said sample tube.

34. A method as claimed in claim 33, further comprising the steps of:

dispensing a fluid into said sample tube before or after said driver drives said sample tube rack in said incremental movements.

35. A method as claimed in claim 33, further comprising the steps of:

controlling a spindle to temporarily remove said sample tube from said sample tube rack, and to rotate said removed sample tube to substantially separate a first component of said cell sample from a second component of said cell sample while allowing said sample tube rack to move along said direction of movement.

36. A method as clamed in claim 33, wherein:

said sample tube rack is substantially circularly shaped and is adapted to support said sample tubes at intervals along a circumferential direction; and

said direction of movement is along said circumferential direction.

37. A method for processing a sample material contained in a sample tube supported by a sample tube rack, comprising the steps of:

moving a spindle in a first direction with respect to an opening in said sample tube, to project said spindle into said opening to temporarily couple said spindle to an interior surface of said sample tube; and

substantially aligning an axis of said spindle with an axis of said sample tube when said spindle is projecting into said opening in said sample tube, to substantially minimize a loading force applied to said interior surface of said sample tube by said spindle.

38. A method as claimed in claim 37, further comprising the steps of:

moving said spindle when said spindle is coupled to said interior surface of said sample tube, to remove said sample tube from said sample tube rack.

39. A method as claimed in claim 37, further comprising the step of:

selectably positioning a sample tube stripping device at a first position with respect to said spindle to permit said spindle to maintain contact with said sample tube, and at a second position at which said sample tube stripping device is adapted to contact said sample tube to separate said sample tube from said spindle.

40. A method as claimed in claim 37, wherein said spindle is further adapted to uncouple from said interior surface of said sample tube, and said method further comprises the steps of:

inserting at least a portion of said spindle into a vessel after said spindle has uncoupled from said interior surface of said sample tube; and

delivering a fluid into said vessel so that said fluid contacts said portion of said spindle in said vessel.

41. A method for removing a sample tube from a spindle, comprising the steps of:

positioning a sample tube stripping device at a first position with respect to said spindle to permit said spindle to maintain contact with said sample tube; and

positioning said sample tube stripping device at a second position at which said sample tube stripping device is adapted to contact said sample tube to separate said sample tube from said spindle.

42. A method as claimed in claim 41, further comprising the step of:

controlling said spindle to move said sample tube into contact with said sample tube stripping device when said sample tube stripping device is positioned at said second position, to enable said sample tube stripping device to remove said sample tube from said spindle.

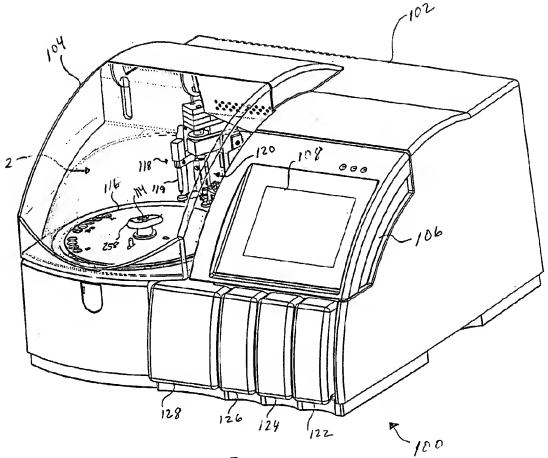


FIG. 1

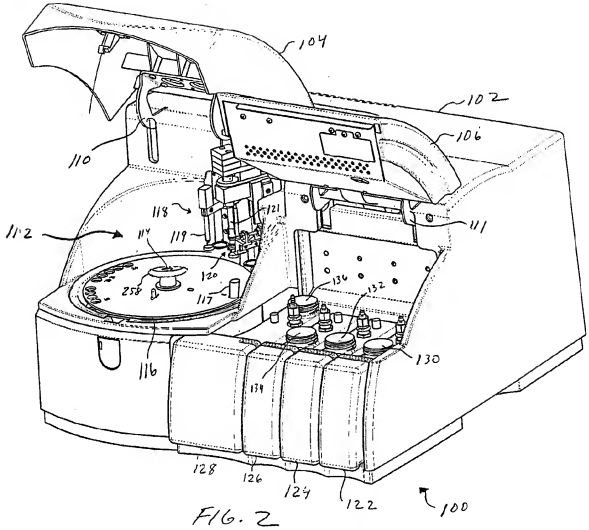

104
102
106
110
118
121
111
112
114
119
120
258
117
136
132
116
130
134
128
126
124
122
100

FIG. 2

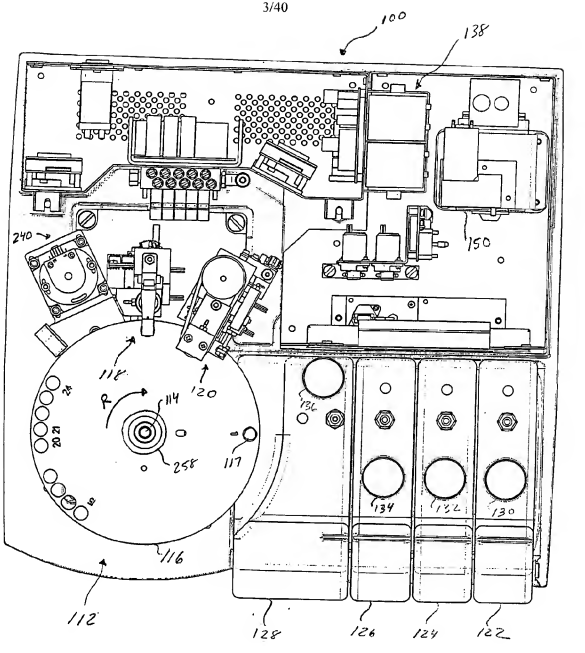

100
138
240
150
118
120
114
R
258
117
116
112
136
134
132
130
128
126
124
122

FIG. 3

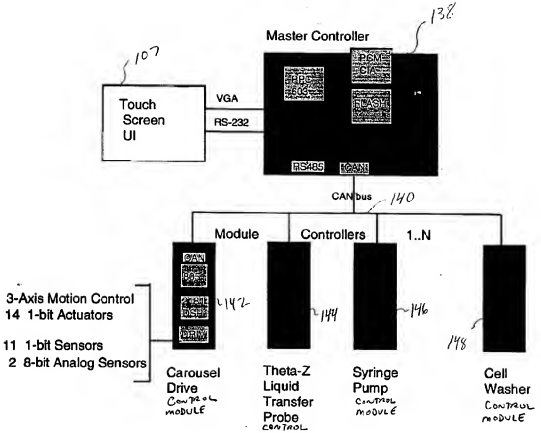
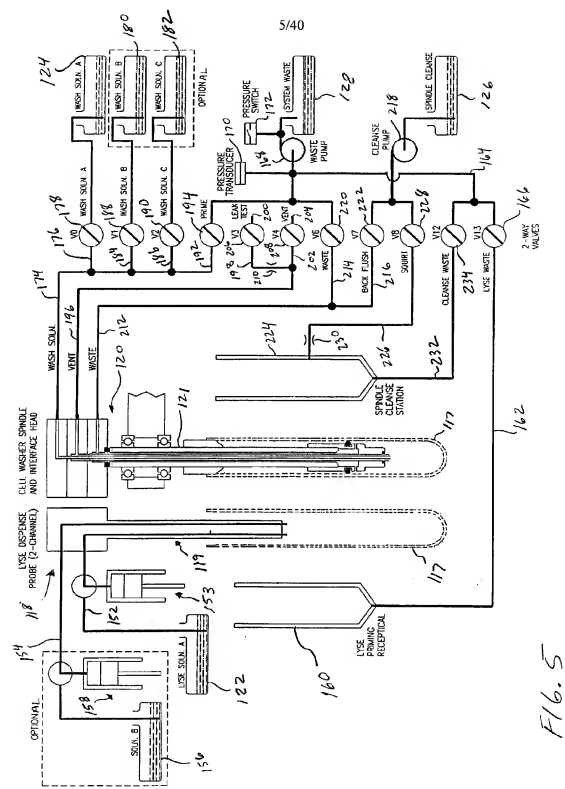
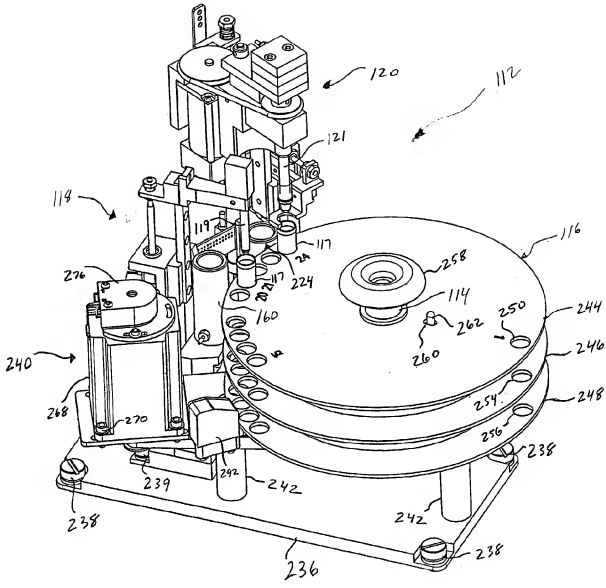

138
Master Controller
107
Touch Screen UI
VGA
RS-232
RS485
CAN
CAN bus
140
Module
Controllers
1..N
3-Axis Motion Control
14 1-bit Actuators
11 1-bit Sensors
2 8-bit Analog Sensors
142
144
146
148
Carousel Drive Control module
Theta-Z Liquid Transfer Probe control module
Syringe Pump control module
Cell Washer Control module

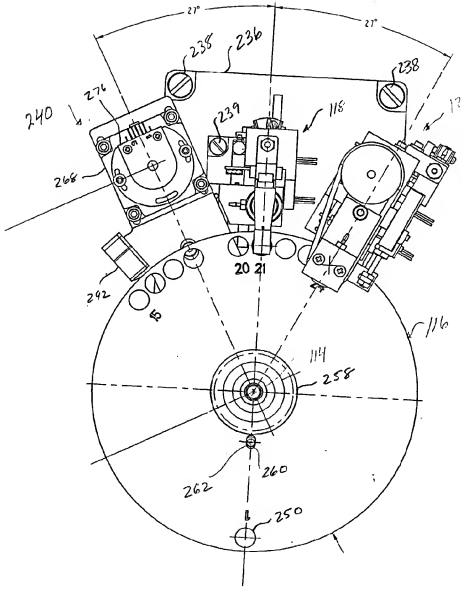
FIG. 4


WASH SOLN. A
WASH SOLN. B
WASH SOLN. C
OPTIONAL
PRESSURE SWITCH
SYSTEM WASTE
WASTE PUMP
PRESSURE TRANSDUCER
CLEANSE PUMP
SPINDLE CLEANSE
V0
V1
V2
V3
V4
V5
V6
V7
V8
V12
V13
2-WAY VALVES
LEAK TEST
VENT
PRIME
WASTE
BACK FLUSH
300ML
CLEANSE WASTE
LYSE WASTE
WASH SOLN
VENT
WASTE
CLU WASHER SPINDLE AND INTERFACE HEAD
LYSE DISPENSE PROBE (2-CHANNEL)
SPINDLE CLEANSE STATION
LYSE SOLN. A
SOLN. B
LYSE PRIMING RECEPTICAL

F/G. 5


120
112
121
118
119
117
116
276
224
258
114
160
262
250
244
240
260
246
268
254
248
270
256
238
239
242
242
238
238
236

F/G. 6


27°
27°
235
236
238
240
274
239
118
120
268
20 21
242
116
114
258
262
260
250

F/G. 7

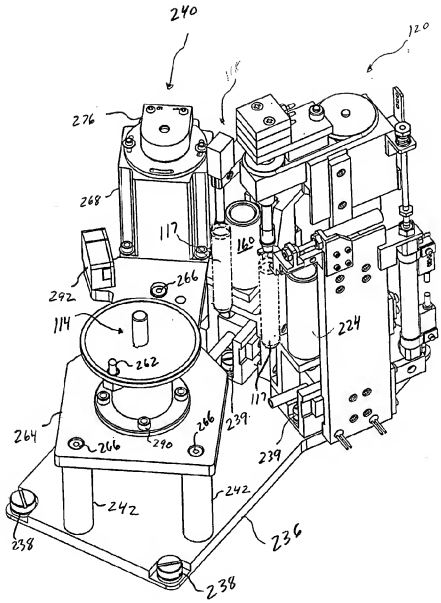

240
120
276
268
117
160
292
266
114
262
224
264
266
290
266
239
117
239
242
242
238
236
238

FIG. 8

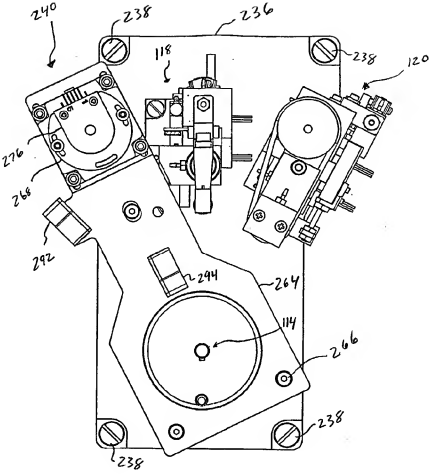


FIG. 9

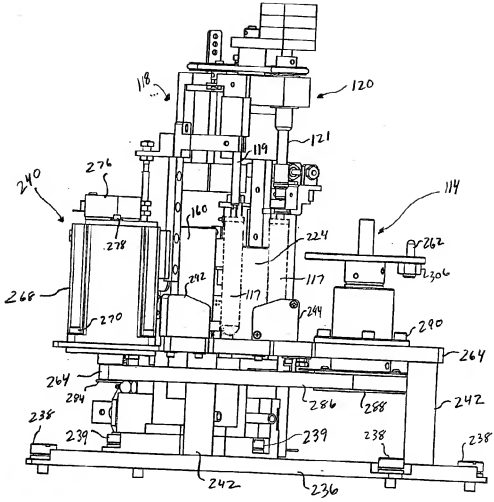

118
120
121
119
276
240
160
278
224
262
306
114
268
292
117
117
244
270
290
264
264
284
286
288
242
238
239
239
238
238
242
236

FIG. 10

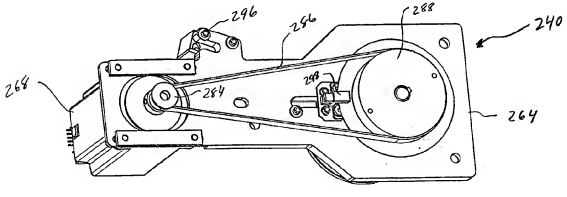

296
286
288
240
268
284
298
264

FIG. 11

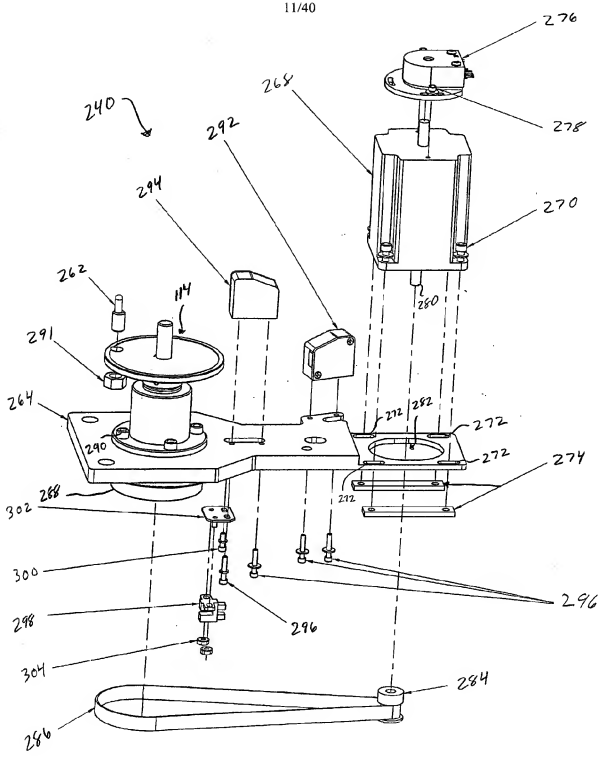

276
278
265
240
292
294
270
262
114
260
291
264
290
272
282
272
272
274
272
302
288
300
296
298
296
304
284
286

FIG. 12

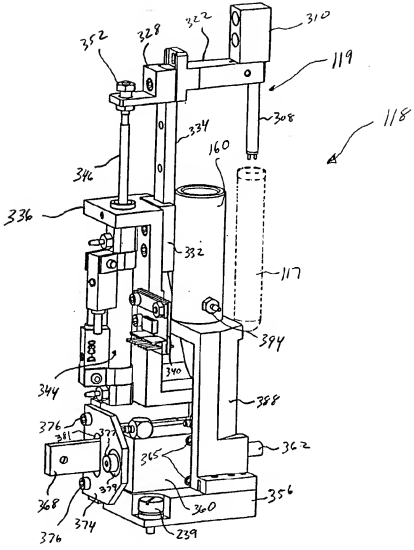

352
328
322
310
119
118
308
334
160
342
336
332
117
394
340
344
358
376
381
372
362
365
377
368
360
356
374
376
239

FIG. 13

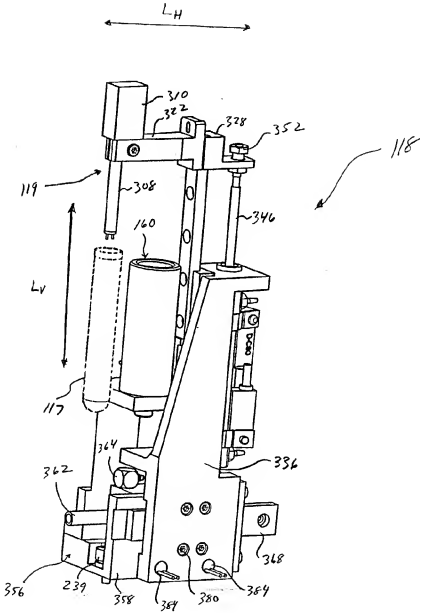

L_H
310
322
328
352
118
119
308
346
160
L_V
117
364
336
362
368
356
239
358
384
380
364

FIG. 14

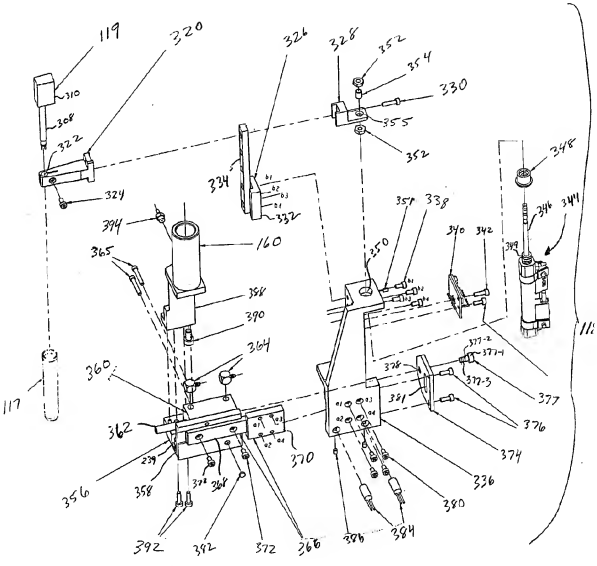
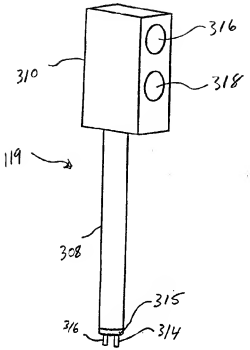
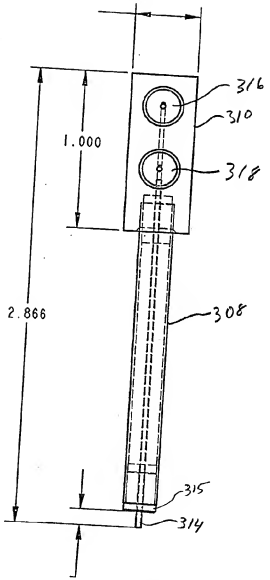

119
320
326
328
352
354
330
355
352
348
324
334
332
350
338
340
342
344
341
394
160
365
358
390
364
360
362
370
356
358
392
382
372
366
386
384
380
336
374
376
377
377-1
377-2
377-3
381
117

FIG. 15


316
310
318
119
308
315
316
314

F16. 16


316
310
1.000
318
2.866
308
315
314

F16. 17

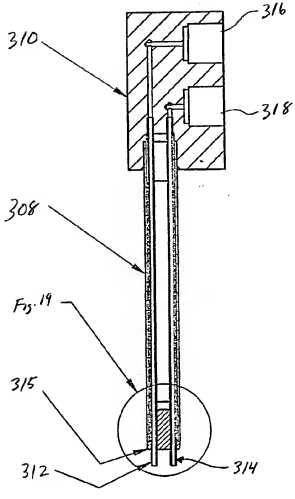


FIG. 18

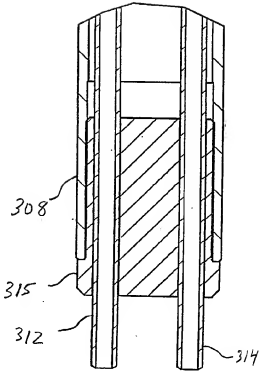


FIG. 19

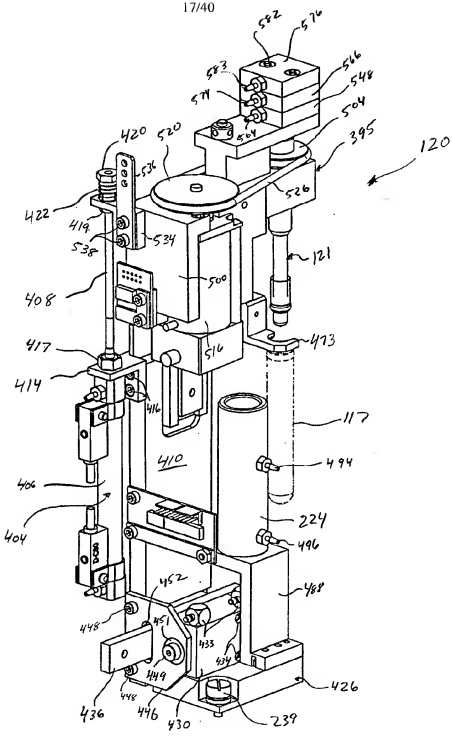

582
574
583
546
548
579
504
569
420
520
395
120
536
526
422
419
534
538
121
500
408
473
417
516
414
416
117
410
494
406
224
404
496
488
452
448
451
433
634
449
426
436
448
446
430
239

FIG. 20

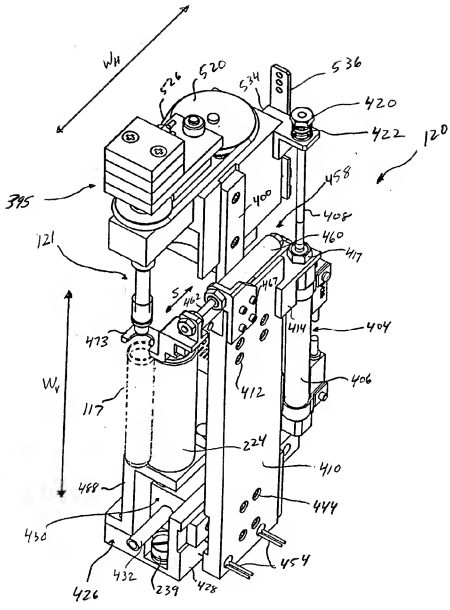

WH
526
520
534
536
420
422
120
458
408
460
417
400
395
121
467
414
404
473
412
406
W_V
117
224
410
488
444
430
454
426
432
239
428

FIG. 21

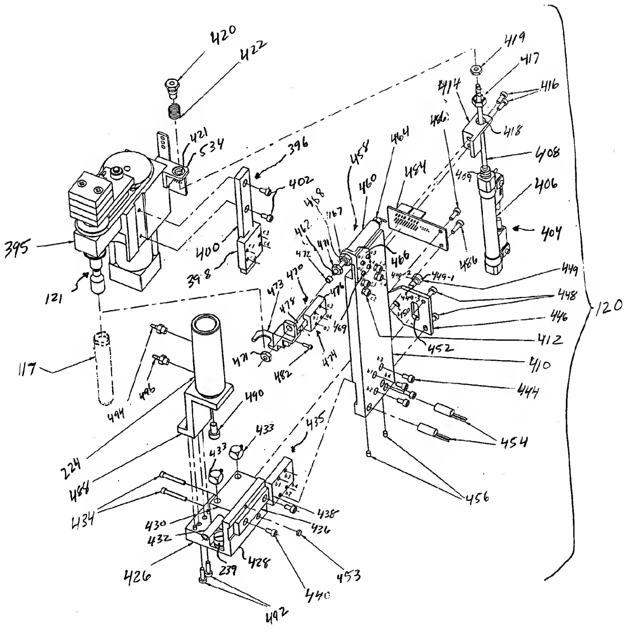
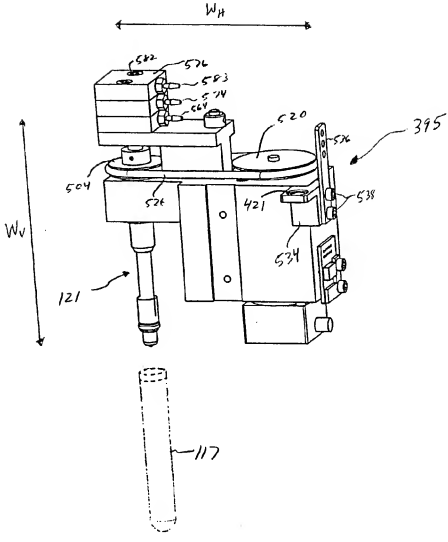


FIG. 22



F/G. 23

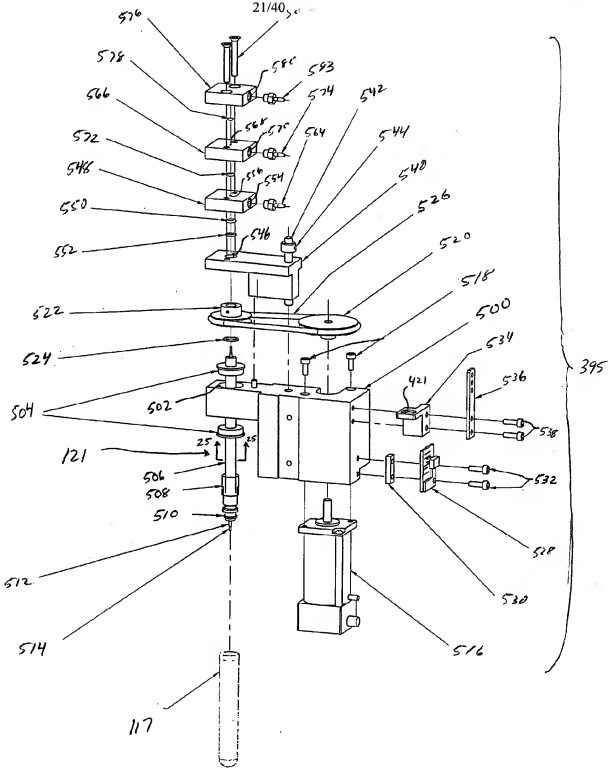

21/40
576
578
566
572
548
550
552
585
583
574
542
568
575
564
544
556
554
548
526
546
520
522
518
500
524
534
536
395
504
502
421
538
121
25
25
506
532
508
510
518
512
530
514
516
117

FIG. 24

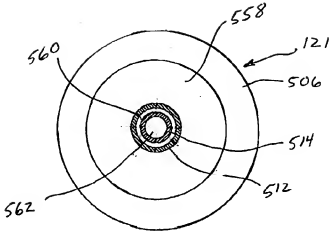


FIG. 25

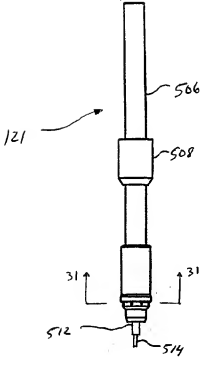


FIG. 26

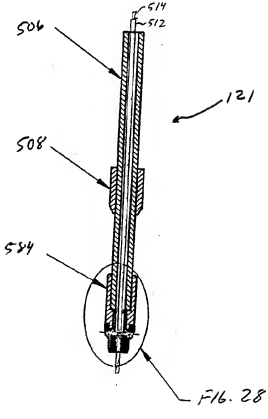


FIG. 27

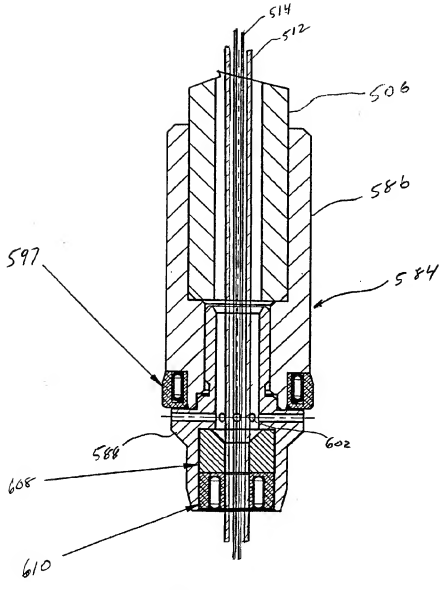


FIG. 28

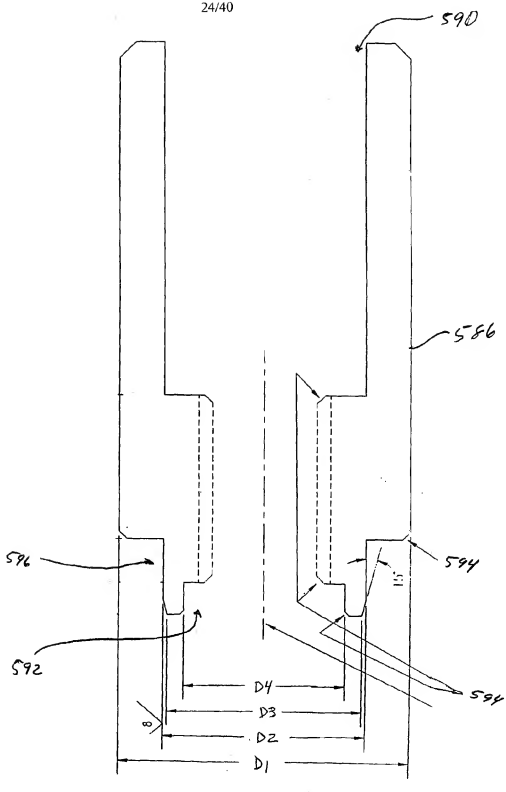


FIG. 29

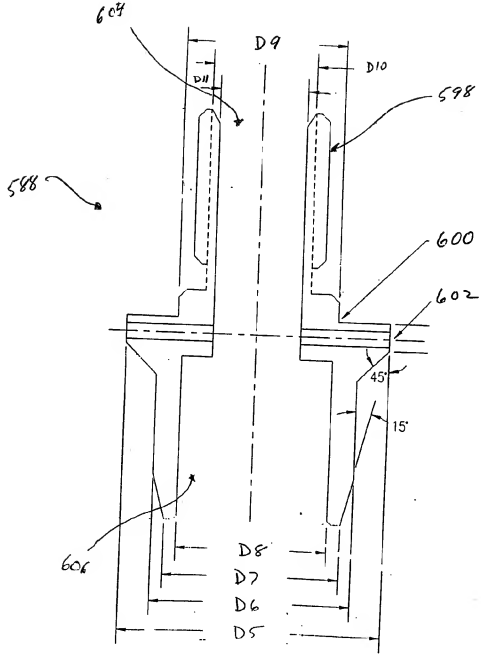


FIG 30

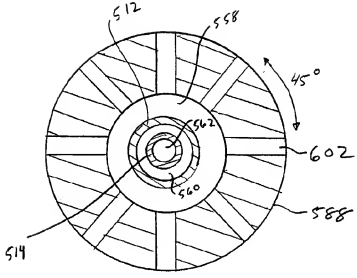


FIG. 31

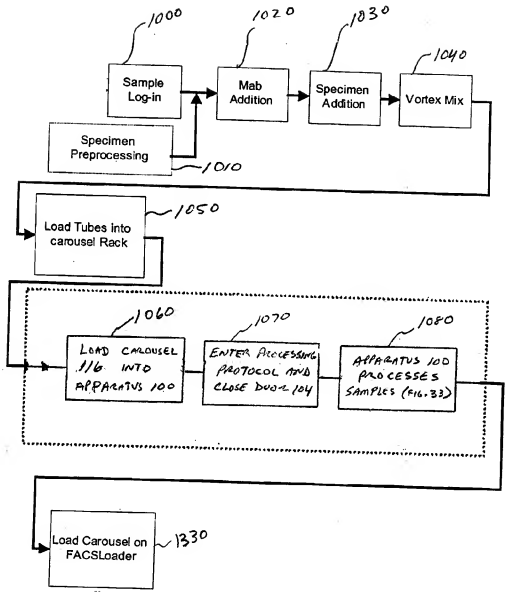

1000
1020
1030
1040
Sample Log-in
Mab Addition
Specimen Addition
Vortex Mix
Specimen Preprocessing
1010
1050
Load Tubes into carousel Rack
1060
1070
1080
LOAD CAROUSEL 116 INTO APPARATUS 100
ENTER ACCESSING PROTOCOL AND CLOSE DOOR 104
APPARATUS 100 PROCESSES SAMPLES (FIG. 33)
Load Carousel on FACSLoader
1330

FIG. 32

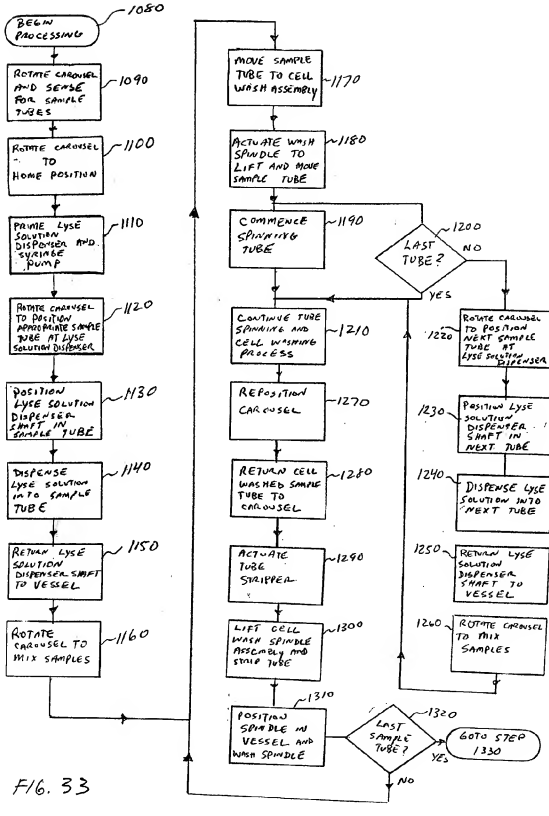

BEGIN PROCESSING
1080
ROTATE CAROUSEL AND SENSE FOR SAMPLE TUBES
1090
ROTATE CAROUSEL TO HOME POSITION
1100
PRIME LYSE SOLUTION DISPENSER AND SYRINGE PUMP
1110
ROTATE CAROUSEL TO POSITION APPROPRIATE SAMPLE TUBE AT LYSE SOLUTION DISPENSER
1120
POSITION LYSE SOLUTION DISPENSER SHAFT IN SAMPLE TUBE
1130
DISPENSE LYSE SOLUTION INTO SAMPLE TUBE
1140
RETURN LYSE SOLUTION DISPENSER SHAFT TO VESSEL
1150
ROTATE CAROUSEL TO MIX SAMPLES
1160
MOVE SAMPLE TUBE TO CELL WASH ASSEMBLY
1170
ACTUATE WASH SPINDLE TO LIFT AND MOVE SAMPLE TUBE
1180
COMMENCE SPINNING TUBE
1190
LAST TUBE?
1200
NO
YES
CONTINUE TUBE SPINNING AND CELL WASHING PROCESS
1210
REPOSITION CAROUSEL
1270
RETURN CELL WASHED SAMPLE TUBE TO CAROUSEL
1280
ACTUATE TUBE STRIPPER
1290
LIFT CELL WASH SPINDLE ASSEMBLY AND STRIP TUBE
1300
POSITION SPINDLE IN VESSEL AND WASH SPINDLE
1310
LAST SAMPLE TUBE?
1320
YES
GOTO STEP 1330
NO
ROTATE CAROUSEL TO POSITION NEXT SAMPLE TUBE AT LYSE DISPENSER
1220
POSITION LYSE SOLUTION DISPENSER SHAFT IN NEXT TUBE
1230
DISPENSE LYSE SOLUTION INTO NEXT TUBE
1240
RETURN LYSE SOLUTION DISPENSER SHAFT TO VESSEL
1250
ROTATE CAROUSEL TO MIX SAMPLES
1260

FIG. 33

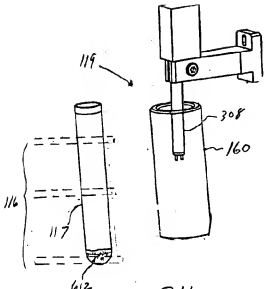


FIG. 34

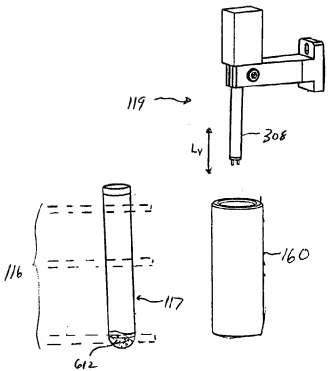


FIG. 35

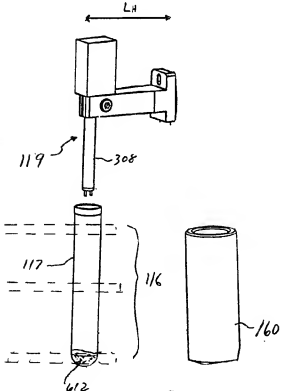


FIG. 36

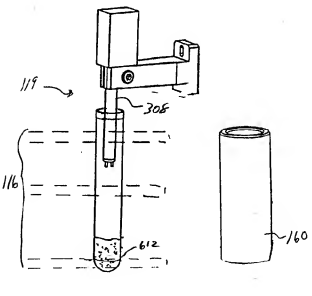


FIG. 37

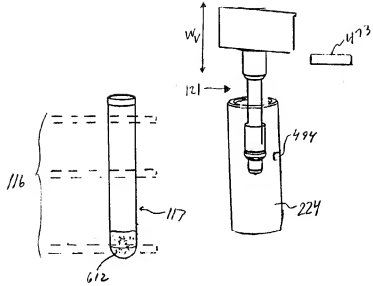


FIG. 38

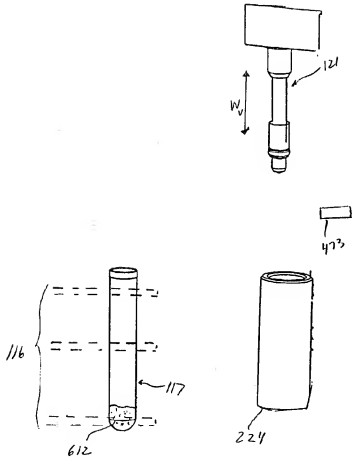


FIG. 39

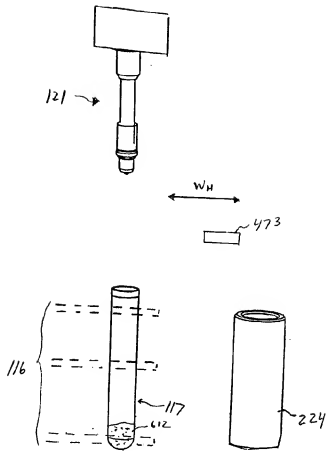


FIG. 40

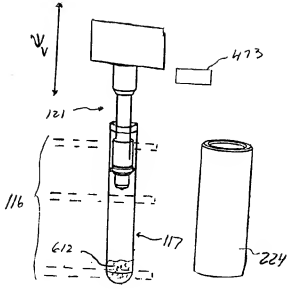


FIG. 41

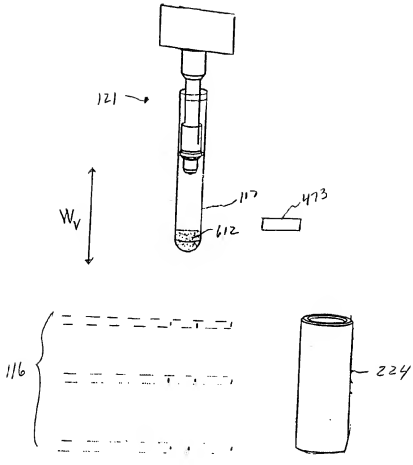


FIG. 42

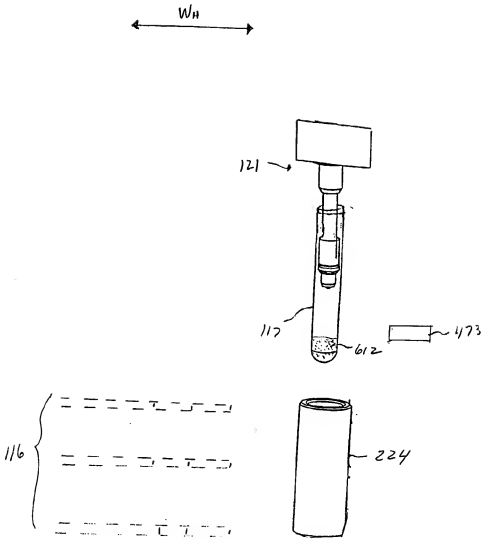


FIG. 43

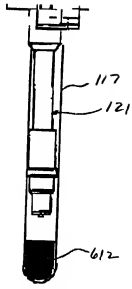


FIG. 44

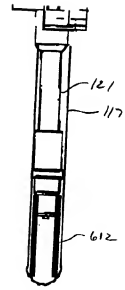


FIG. 45

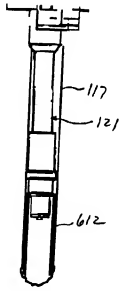


FIG. 47

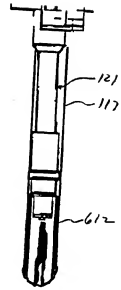


FIG. 48

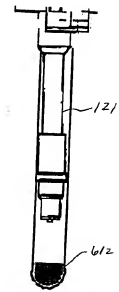


FIG. 50

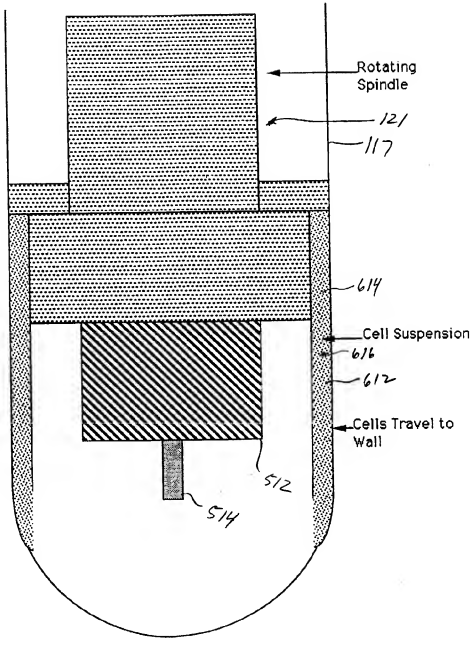

Rotating Spindle
121
117
614
Cell Suspension
616
612
Cells Travel to Wall
512
514

FIG. 46

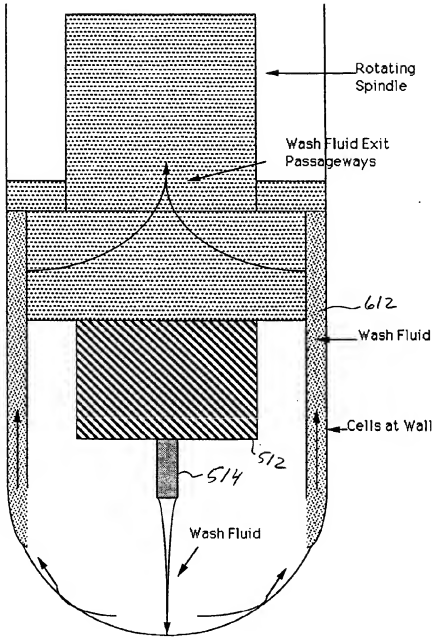

Rotating Spindle
Wash Fluid Exit Passageways
612
Wash Fluid
Cells at Wall
512
514
Wash Fluid

FIG. 49

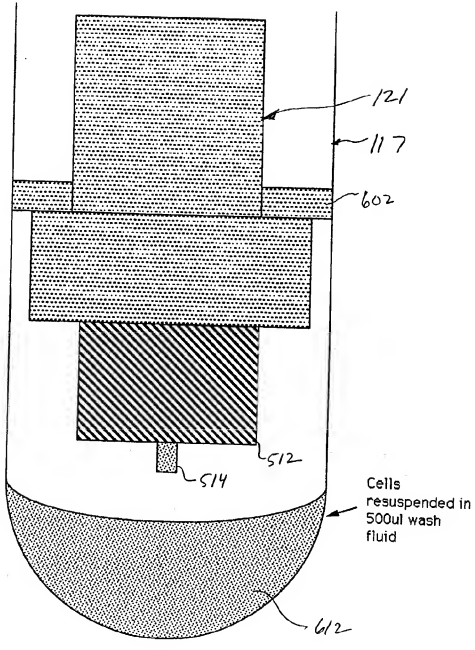

121
117
602
512
514
Cells resuspended in 500ul wash fluid
612

FIG. 51

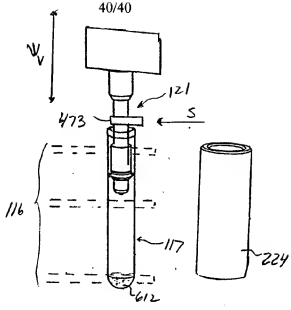


FIG. 52

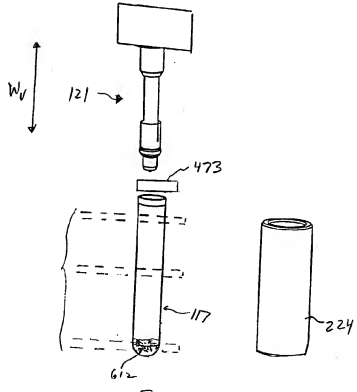


FIG. 53

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/32041

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :G01N 35/02
US CL :Please See Extra Sheet.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 422/63, 64, 72, 81, 100, 101; 436/ 43/, 45, 47, 48, 49, 54, 63, 175, 177, 180; 366/ 19; 494/16

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,721,141 A (BABSON et al) 24 February 1998, entire document.	1-5, 7, 21-25, 29-31
X ---- Y	US 4,007,011 A (GREAVES et al) 08 February 1977, entire document.	9-10, 12, 33-34, 36 ---------- 11, 35
X ---- Y	US 5,840,253 A (CHASE et al) 24 November 1998, entire document.	13-14, -------- 1-8, 21-32
Y	US 5,424,037 A (ZIMMERMANN et al) 13 June 1995, entire document.	1-8,15-32, 37-42

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 09 FEBRUARY 2001	Date of mailing of the international search report 22 MAR 2001
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer PATRICIA K. BEX Telephone No. (703) 308-0661

Form PCT/ISA/210 (second sheet) (July 1998) *

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/32041

A. CLASSIFICATION OF SUBJECT MATTER:
US CL :

422/63, 64, 72, 81, 100, 101; 436/ 43/, 45, 47, 48, 49, 54, 63, 175, 177, 180; 366/ 19; 494/16